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Municipal-Scale Thermal Processing of Solid Wastes

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MUNICIPAL-SCALE THERMAL PROCESSING
OF SOLID WASTES

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FOREWORD

This report has been developed to update *Municipal-Scale Incinerator Design and Operation* formerly titled "Incinerator Guidelines--1969" (SW-13ts). Significant developments in the area of resource conservation through the use of thermal processing have made the earlier publication obsolete.

With the promulgation of the "Standards of Performance for New Stationary Sources" (40 CFR 60) and the "Guidelines for the Thermal Processing of Solid Wastes" (40 CFR 240) the technology of incinerating solid wastes has undergone many changes. The most notable change is a decline in the number of operating facilities due to the stringent air pollution control methods needed to meet standards. In 1972, there were 193 thermal processing facilities in operation; in 1979, the number had declined to 108.

It is our intention to show the state-of-the-art of incineration with this publication. We feel that public officials and private groups will be able to use this information to develop environmentally acceptable and economically sound solid waste management systems.

--SHELDON MEYERS
Deputy Assistant Administrator
Office of Solid Waste

PREFACE

Until recent years solid waste incineration has been considered as an expensive alternative to landfilling for disposal of municipal solid waste, to be used only when landfill sites were not readily available. Today thermal processes, which include incineration, pyrolysis, and combined refuse/fossil fuel combustion, with energy and/or resource recovery can be considered as competitors for landfilling, both because of the increased cost of landfilling performed in an environmentally sound manner and because of the increased value of energy, metals, and glass which can be extracted from municipal solid waste.

However, thermal processing of solid wastes and associated resource recovery systems are in a state of transition from developmental to fully operational stages. The performance of waterwall incinerators which generate steam has been fully proven both in Europe and North America. However, no waterwall incinerator projects in the United States are yet on sound footing with regard to external steam sales. Three modern waterwall incinerators in the United States are simply condensing all the steam generated, except for the small amounts being used internally. A new waterwall incinerator recently started up will supply steam to 27 downtown buildings for heat and air conditioning. Hopefully, this project will succeed. Because of imbalance between supply and demand for energy, only projects which have been planned with extreme care will fully meet expectations.

On the other hand, combined refuse/fossil fuel firing in existing steam boilers makes use of already available facilities for energy distribution and already available markets. The uncertainties which do exist are mainly technical. Although a large scale test has been conducted on a refuse/coal fired boiler, each new test with varying boiler designs, other types of coal, and oil firing raises technical questions of corrosion, erosion, fuel handling, air pollution control, and others. Careful engineering will be required to insure broad success of this promising approach to thermal processing with energy recovery.

Several pyrolysis processes are available for converting municipal solid waste to fuels. One plant, recently started up, converts the fuel to steam; another is undergoing detailed design; while a third has been undergoing tests in a large scale prototype. While the fuels produced are not conventional in the sense of fuels widely used today, they should find ready outlets under contract. The importance of good project and contract planning holds as true for pyrolysis processes as for steam generating incinerators.

Resource recovery can enhance any of the thermal processes discussed above. Rapidly emerging technology should eventually allow recovery of not only ferrous metals, but also color-sorted glass, aluminum, other metals, and even paper fiber. Some resource recovery plants may separate a combustible fraction which can be transported elsewhere for use in pyrolysis or incineration with energy recovery.

Some of the steps in resource recovery can be considered proven, for example preparation of a combustible fraction, and ferrous metal recovery from either mixed refuse or from incinerator residue. However, no complete system recovering the full range of potentially valuable energy and materials is yet fully operational and economical to the point of paying for solid waste disposal. Even with technical success, many marketing and end use problems will remain for some time to come, as industry and others become accustomed to unfamiliar materials and energy forms available in municipal solid waste.

The terms "municipal solid waste," "solid waste," and "refuse" are used interchangeably in this publication. No special significance should be ascribed to the use of a specific term unless it is further modified, e.g. "prepared refuse," "shredded solid waste," etc.

Norman J. Weinstein
Richard F. Toro
December 4, 1975

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Many people have contributed to the concept and contents of this publication. An earlier publication, MUNICIPAL-SCALE INCINERATOR DESIGN AND OPERATION (1969), by Jack Demarco, Daniel J. Keller, Jerold Leckman, and James L. Lewton was used extensively. Other U.S. Environmental Protection Agency personnel who participated at various stages include William C. Achinger, Edward L. Higgins, Harvey Rogers, and Steven Hitte, Project Officer.

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Thanks are also due to the many incinerator operators and others active in thermal processing who gave of their time to provide RECON SYSTEMS with maximum insight into this aspect of municipal solid waste management.

The list of operating thermal processing plants in Appendix A was contributed by the American Society of Mechanical Engineers.

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CHAPTER I

THERMAL PROCESSING OF SOLID WASTES: AN INTRODUCTION

A municipal solid waste management system consists of a number of steps, starting with collection and continuing through transportation, pretreatment, treatment, environmental controls, disposal of residues, and recycle of byproducts. This publication deals with municipal solid wastes from the point of delivery to a thermal processing plant to the discharge of residues and recycle of byproducts from the process. The following introductory discussion highlights the heart of the system, the thermal processing step.

The primary objective of any effective waste management system is disposal, while avoiding or minimizing damage to the environment. This objective may be met by reclaiming useful materials and/or conversion of waste components to benign or useful materials. For example, in the sanitary landfill of municipal solid wastes, the wastes are dumped onto specially chosen and prepared sites, compacted, isolated into cells using a cover such as earth, and allowed to slowly change by biochemical action to a complex, but hopefully benign, material allowing subsequent use of the land site.

Thermal processing of solid wastes is the elevated temperature treatment of those wastes in suitably designed equipment so as to convert the waste components into benign or useful materials. In practice, thermal processing may be accomplished in the presence of substantial quantities of added oxygen (usually air) - in a process called incineration; or thermal processing may be accomplished with little or no oxygen added to that already chemically bound within the waste.

Historically, the only thermal process of importance with respect to municipal solid waste has been incineration. In an effective incineration process, the combustion gases are composed almost entirely of carbon dioxide, water, nitrogen, and oxygen, all of which are normal atmospheric constituents. The residue should contain little or no combustible material.

In recent years other thermal processes have been developed to produce products which are useful as fuels, and possibly as chemical raw materials. These processes can be subdivided into three categories: simple pyrolysis, where little or no oxygen is added to the thermal treatment zone; partial oxidation, where appreciable amounts of oxygen or air are added, producing substantial quantities of carbon monoxide and hydrogen in addition to carbon dioxide and water; and reduction, where either hydrogen or carbon monoxide is reacted with solid waste. All of these categories are usually referred to as pyrolysis, and this practice will be followed here.

This publication will deal mainly with refractory incinerators, and with modern evolving incineration processes and pyrolysis processes in which resource and energy recovery is practiced.

The selection of a suitable process, and some of the highlights of the major types of thermal processes which are commercially available, are discussed in the following paragraphs.

Selection of a Suitable Process

In the current social and regulatory environment, the choice among alternative solid waste disposal processes will normally be made by considering impact on local and regional environment, local and regional optimum land use, net processing costs, and other specific local problems. For example, one should consider the desirability of dealing with secondary sewage sludge and special industrial and commercial wastes, and special administrative and operating problems. The choice may also be colored by the attitude of the local community toward environmental quality and resource conservation.

In the evolving technology of municipal solid waste disposal, the state of development of new processing techniques must also be a prime consideration in process selection. For example, in its current state of development (1975), the choice of a pyrolysis process would necessarily entail greater risks than the choice of a proven incineration process, though the risk might be worth taking because of potential economies or because of questions of resource conservation.

It is necessary to make a realistic up-to-date assessment of the status of all the options available in order to select the best process for the needs of a particular community. Recycling opportunities must be considered as an integral part of such an assessment. It is a prime purpose of this publication to acquaint those responsible for such decisions with the current state-of-the-art, and with important factors which should be considered in selecting a suitable municipal solid waste thermal processing system.

Incineration Processes

Incineration has been the traditional competitor to landfill in areas where insufficient suitable landfill capacity is available within an economic haul distance. Although most incinerators built in the past could not meet today's performance criteria, a well-designed, carefully operated incinerator reduces the weight and volume of municipal solid waste to produce a residue which can be used as a fill material. Table 1 compares volume reduction obtainable by thermal processes with that encountered in sanitary landfill. Gases discharged to the atmosphere are treated to meet governmental standards for emission of particulates and chemical constituents. Water used for effluent gas scrubbing or to transport residual solids should be recycled and/or treated to produce an essentially pollution-free effluent. New incinerators in the United States are now normally built to recover heat in the form of steam, instead of discharging the combustion heat to the atmosphere as hot flue gas.

Table 7

CALCULATION OF VOLUME REDUCTION BY VARIOUS SOLID WASTE DISPOSAL SYSTEMS

	Original Volume as Fractions	Reduction Factor	Final Landfill Volume as Fraction of Original Volume
Sanitary Landfill[7]			
Incinerable Waste*	0.8	0.166	0.133
Bulky & Non-Incinerable Waste	0.2	0.5	0.100
	1.0		0.233
Sanitary Landfill with Shredding and Resource Recovery			
Total Waste*	1.0	$(0.125^2)^+$	$(0.125)^+$
Refractory Incineration[7]			
Incinerable Waste*	0.8	0.0145	0.012
Bulky & Non-Incinerable Waste	0.2	0.5	0.100
	1.0		0.112
Incineration with Shredding and Resource Recovery			
Total Waste*	1.0	$(0.088^2)^+$	$(0.088)^+$
Pyrolysis Processes with/without Resource Recovery#			
Total Waste*	1.0	$(0.004\text{-}0.03)^+$	$(0.004\text{-}0.03)^+$

* Bulk density assumed to be 89 kilograms per cubic meter (150 lbs/cubic yard).

+ Numbers in parentheses are somewhat speculative since little data is available for confirmation.

# Numbers for pyrolysis do not include ash contents of liquid or solid fuels which will become residual products when the fuel is burned.

Refractory Incinerators. Most of the incinerators which have been built in the United States do not practice energy recovery. They utilize a refractory furnace where the solid waste is burned with air. The furnace may be a fixed hearth type, or an inclined rotary kiln. Excessive temperatures are avoided by using a quantity of air in excess of that theoretically required for combustion, the excess air serving as a cooling medium. Average furnace exit temperatures are usually in the range 760 to 1010 C (1400 to 1850 F).

Grates are provided in fixed hearth furnaces as a passage for underfire air, while supporting the solid waste being burned. The most common of the designs available are the many types of moving grates which transport the solid waste and residue through the furnace and, at the same time, promote combustion by inducing agitation and passage of underfire air.

Incinerators With Heat Recovery. The simplest form of energy recovery is the use of a waste heat boiler with a conventional refractory incinerator, that is extracting heat from the flue gases, usually to make low pressure steam. A more effective type of heat recovery unit utilizes furnace walls made of closely spaced steel tubes welded together, with water or steam circulated through the tubes to extract heat generated during combustion. This procedure not only leads to heat recovery, but allows a major reduction in air requirements, thus reducing the size of air pollution control equipment and other facilities. Where high pressure steam is made, it can be used to drive turbines for electric power production. The decision as to energy recovery is governed primarily by the nature of the market for steam, including demand patterns and potential value.

Slagging Incinerators. If the combustion air flow for a given burning rate of solid waste in a refractory incinerator is reduced, the combustion temperature increases. At a combustion temperature of about 1600 C (2912 F), a molten residue is obtained, which, when cooled, provides a dense inert material useful as a landfill. The other advantages of this reduction in combustion air flow are the reduced gas volume, simplifying air pollution control, and the more effective combustion at high temperature. Slagging, high temperature, incinerator systems are in the development stage.

Suspension-Fired Incinerators. Extensive size reduction of the solid waste allows furnace designs analogous to pulverized coal steam boilers commonly used by the electric utilities and large industrial plants. The pulverized waste is suspended in an air stream and introduced into the combustion zone, where burning is very rapid. Unlike more conventional incinerators, the major portion of the residue or flyash is carried by the hot flue gases out of the combustion zone directly to the air pollution control solids recovery equipment. A combination refuse/coal combustion system which takes advantage of existing coal-fired suspension type boilers has been undergoing large-scale demonstration.

Fluidized Bed Incinerators. The fluidized bed is a special form of suspension-fired incinerator where the combustion is carried out in the presence of a suspended bed of inert solids whose behavior is analogous to that of a fluid. The fluidized bed aids contact between the air and the solid waste, improving combustion. Agglomeration of the flyash may also be promoted, improving particulate recovery. A system for extracting electric power by expansion of flue gases from an elevated pressure fluidized bed is under development.

Pyrolysis

As discussed earlier in this Chapter, little or no air is introduced into the elevated temperature pyrolysis chamber. Instead of combustion, a complex series of decomposition and other chemical reactions take place. Pyrolysis of municipal solid waste produces low sulfur gaseous, liquid, and solid products which are potentially useful as fuels or chemical raw materials. The nature of these products depends primarily on the composition of the waste, pyrolysis temperature, pressure, and residence time.

Also, unlike incineration which is highly exothermic, the addition of heat to the pyrolysis chamber is usually necessary. The method of heat introduction is a major distinguishing factor between various pyrolysis processes. For example, auxiliary fuel combustion, highly preheated air, circulating heated solids, and limited oxygen introduction to produce heat by oxiding part of the carbon present in the waste have all been used.

The elimination of inorganic constituents of the solid waste is a useful step in pyrolysis processes to avoid contamination of products. Therefore, separation steps to recover glass and metal byproducts fit naturally into pyrolysis schemes.

The control of air pollution in pyrolysis processes is eased to some extent, as compared to incineration, because of the reduced volume of gases to be treated. However, water pollution control problems may be more serious than in incineration due to extensive production of water and water soluble inorganic chemicals which must be disposed of. This is a particularly difficult problem in low temperature pyrolysis where liquid yields are high.

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CHAPTER II

BASIC DATA FOR DESIGN

Reliable basic design data is indispensable, not only for successful design, but also as an aid in the selection of a specific thermal processing system. Much of the data required should be available from a previously developed solid waste management plan.[1] The data to be discussed in this Chapter is that required to provide a sound basis for design, as distinct from engineering data used for the detailed construction drawings.

The data required encompasses both the current status of municipal solid waste problems and projections for the future. All of the physical factors of solid waste generation and characteristics, and of site problems, must be considered, as well as constraints such as environmental regulations. In addition, possible markets for solid waste byproducts should be investigated.

Regulations

Thermal process designs must meet regulations intended to preserve the quality of the environment, and the health and safety of all those who are associated with the operation or who live in the vicinity of the plant. Designs should adhere to EPA's "Guidelines for Thermal Processing" which are intended to provide for thermal processing with minimum adverse impact on the environment.[2] The guidelines apply to facilities which are designed to process more than 50 short tons/day. Thermal processing facility operations are expected to conform to the most stringent Federal, State, or local standards that are legally applicable to the operation of such facilities.

Air Pollution. Particulate matter emissions to the atmosphere from new incinerators processing more than 50 tons/day are specifically limited by EPA's "Standards of Performance for New Stationary Sources."[3] There are presently no specific Federal regulations for gaseous emissions from incinerators, nor are there Federal regulations covering emissions from pyrolysis units. There are proposed Federal standards for petroleum storage vessels which are applicable to such vessels containing pyrolysis liquids.[4] Hazardous emission standards for asbestos, beryllium, and mercury, could possibly affect thermal process designs in the future.[5] State or local air pollution standards which must be met are sometimes more stringent than the Federal standards.

Air pollution from thermal processing systems is also governed by Federal ambient air quality standards, which establish the maximum amount of each pollutant that will be permitted in the atmosphere consistent with public health and welfare. National standards have been set for sulfur oxide, particulate matter, carbon monoxide, hydrocarbons, photochemicals, and nitrogen oxide. Other air quality standards, such as for mercury, lead, and nitrogen dioxide, may be established in the future. The States have the broad responsibility of deciding which activities to regulate or prohibit in order to achieve the national standards. Therefore, in planning thermal processing systems, one should investigate State implementation plans and existing State regulations, as well as local regulations.

Water Pollution. Under the 1972 amendments to the Federal Water Pollution Control Act, EPA is directed to publish regulations establishing guidelines for effluent limitations, and effluent limitations for toxic pollutants. Permits are required for each establishment discharging effluent into water courses, but no permit is required for discharge into a municipal waste system, except that pretreatment standards must be complied with. Since all State laws governing water pollution must be met, even when more stringent than Federal standards, both State and local regulations must be investigated.

Solid Wastes. EPA's "Guidelines for Land Disposal of Solid Wastes" provide a design basis for this approach.[7] Ocean dumping is prohibited except by Federal permit. At this time, disposal of solid residues is governed primarily by State and local regulations.

Noise. The Noise Control Act of 1972 authorizes EPA to establish Federal noise emission standards for products distributed in interstate commerce. Therefore, the operator of a thermal processing facility can look forward to a diminishment of "unwanted sound," but he assumes no specific responsibility under this law. State and local noise regulations will affect the design basis.

Occupational Safety and Health. Employers excluded under provisions of the Occupational Safety and Health Act of 1970 include the United States or any State or political subdivision of a State.[8] Municipal thermal processing plants are thereby excluded. However, municipal plant operators should be familiar with these standards as useful guidelines, and as a possible basis for future Federal, State, or local regulations. OSHA standards cover noise, ventilation, walking and working surfaces, means of egress, elevators, hazardous materials, personnel protective equipment, sanitation, physical hazards, medical services, fire protection, compressed gas equipment, materials handling, machinery guards, electrical equipment, and other safety considerations. Many of these are also regulated by State and local codes and are the subject of insurance standards.

Other State and Local Codes. Existing State and local construction codes governing the installation of civil, mechanical, sanitation, and electrical facilities must be complied with. These and aesthetic regulations may limit the options available for building and state design.

In the ideal situation, a site has already been specified by an earlier master plan[1] or as a result of a solid waste planning study. If this is not the case, zoning regulations may limit the site choice and directly or indirectly affect building and facilities designs, for example, through problems of space availability and transportation, or problems associated with meteorological, geologic, or soil conditions. Incinerators have generally been built in areas zoned for industrial use. Some future thermal processing systems which are extremely well designed and planned may be built in commercial or residential areas, but, in gathering basic data for design, the planner should be aware that existing industrial zoning may limit his options as to site and design.

Site Data

A few basic data considerations for site selection will be considered in this Section. A most detailed discussion, including the question of public acceptance, will be reserved for Chapter IV, "Site Selection."

As mentioned above, the choice of site is most affected by previous land use planning, and by solid waste transportation considerations. Information on soil, and geological and meteorological conditions must be gathered from local and State sources. Some information may also be available from Federal sources, for example, the Soil Conservation Service of the Department of Agriculture, the Geological Survey of the Department of the Interior, or meteorological aspects of air pollution control from the Environmental Protection Agency.

Nature of the Community

Knowledge of the community is one of the key variables in predicting solid waste characteristics and loadings to thermal processing facilities. For example, comparative data for three locations are shown in Table 2, all for residential and commercial refuse.[7]

Seasonal variations also occur. Variations are even larger for localities handling industrial wastes or other specialized wastes. Where possible, existing wastes should be carefully sampled and analyzed using available techniques.[9, 10]

Where sampling and analysis are not possible, predictive techniques may be used. [illegible] will be most successful when complete community data are available. For example, conditions of climate, tourism, the presence of industries, commercial, governmental, and institutional facilities, the degree of urbanization, and other special disposal problems should be known. Detailed information on varying land uses and proposed future uses is important.

Table 2

AS-RECEIVED MUNICIPAL SOLID WASTE COMPOSITION DATA[7]

	Weight Percent		
	Weber County, Utah	Alexandria, Virginia	San Diego, California
Food Wastes	8.5	7.5	0.0
Yard Wastes	4.2	9.6	21.1
Miscellaneous	6.9	3.4	--
Glass, Ceramics	4.6	7.5	8.3
Metal	8.4	8.2	7.7
Paper Products	61.8	55.3	46.1
Plastics, Leather, Rubber	2.5	5.1	6.0
Textiles	2.0	3.7	3.5
Wood	2.2	1.7	7.5
	100.	100.	100.

Population

Determining the present and future population to be served has several important purposes. An appraisal of population density aids in locating the incinerator at the most economic site. Another important use of population data is to estimate the quantity of wastes to be handled and, therefore, the thermal processing plant capacity required for the designated area.

The population estimates should include the transient, commuter, and permanent domestic population at the time the survey is made, when the plant is to be opened, over the projected life of the facility, and seasonal population variation. In determining the future population to be served, the designer should consider the possible inclusion of adjoining developed areas within the metropolitan complex and the possible servicing of new areas as they develop.

Standard techniques are available for estimating current population. Some correlate the historical census records with an historical record of population indicators, such as number of water meters, water consumption, or other utility or commercial consumption. Other methods relate community growth to historical growth of nearby industries or other communities. Statewide population projections can be obtained from the U. S. Bureau of the Census. Regional, County and local projections often can be obtained from local, district, County, or State planning departments and from local utility companies.

Solid Waste Quantities

The quantity of a community's solid waste will vary markedly with the climate, season, character of the community, the extent and type of commercial, industrial, institutional and residential developments as well as the extent of usage of on-site incinerators and food waste grinders.

Per Capita Quantities. The continuing increase in the quantity of solid waste produced in the United States is attributed not only to increased population, but also to increase in per capita generation. The wide spread in the ranges of solid waste collected (Table 3) points out the need for local studies. Actual weighing and analysis of waste delivered to existing disposal sites is desirable. Projections of a per capita urban disposal burden have been made (Figure 1), but it must be emphasized that this projection should not be used for a specific municipality, and industrial wastes must be considered as well.[7]

Weekly and Seasonal Variations. Seasonal fluctuations occur in the amount of solid waste generated and collected within the community and must be considered. This can be done by plotting weekly waste quantities averaged over 4-week periods. The fluctuations in waste quantities occur in yearly cycles, the maximum quantity almost always occurring during the warmer months.

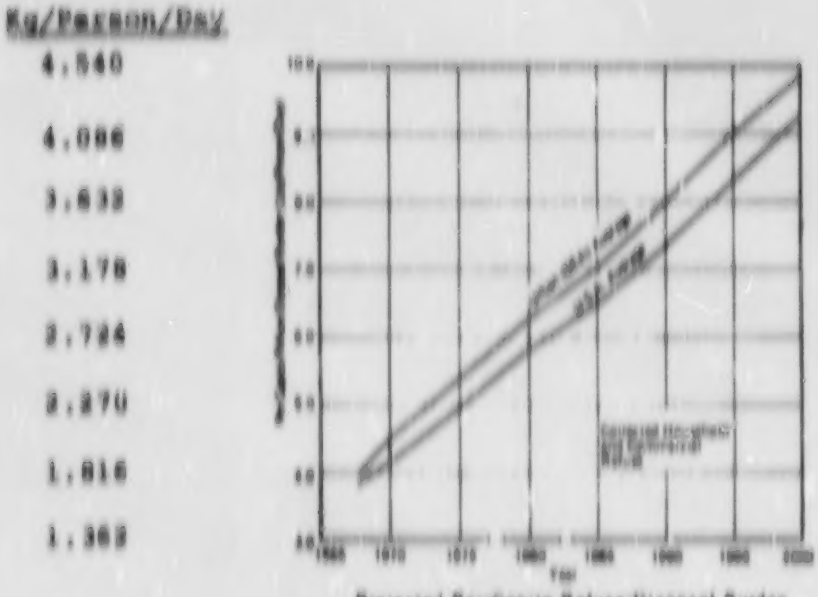
Table 3

SOLID WASTE COLLECTED*

Type	Quantity Per Capita Per Calendar Day kilograms (pounds)
Residential (domestic)	0.7 - 2.3 (1.5 - 5.0)
Commercial (stores, restaurants, businesses, etc.)	0.5 - 1.4 (1.0 - 3.0)
Incinerable bulky solid wastes (furniture, fixtures, brush demolition, and construction wastes)	0.1 - 1.1 (0.3 - 2.5)

* From Municipal-Scale Incinerator Design and Operation (1969). See reference 1 in Chapter 1.

FIGURE 1[7]



Projected Per-Capita Refuse-Disposal Burden

Because of many influences, the magnitude of fluctuations is significantly different from one community to another. Factors that influence variation are climate, weather, geography, tourism, holidays, consumption habits, collection procedures, and community size. Four-week averages in waste generation within a community commonly are in the range of ±10 percent of the average weekly waste quantity; weekly variation in any year seldom exceeds 25 percent of the average weekly quantity for that year.

Sizing. Because of large daily fluctuations in solid waste quantities, a thermal processing system should be sized on the basis of weekly quantities of solid waste to be processed. Storage pits should be designed to handle daily peaks.

One sizing method is based on the average weekly delivery for the highest 4-week period projected for the design year. Another method of sizing is based on the use of a standard frequency diagram using weekly solid waste quantities and a time period of a year (Figure 2). With the use of a plot of this type, the size is based on the weekly solid waste quantity that will be exceeded a given percent of the time during a year. If the design was to be based on a weekly quantity that was exceeded 5 percent of the time, a weekly solid waste quantity corresponding to 95 percent would be selected from the frequency diagram.

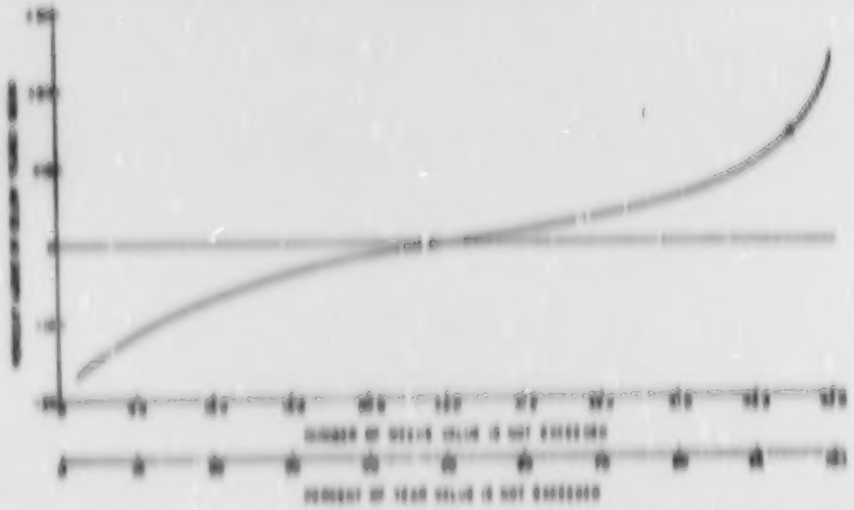
In sizing a thermal processing facility, the fact should also be considered that it will not operate continuously over the planned period. Past experience indicates that incinerators require about 15 percent downtime for repairs and maintenance. Pyrolysis operating factors have yet to be determined.

Another factor to be considered in sizing a thermal processing unit is the possibility of selective acceptance of wastes and of resource recovery. For example, although difficult to implement, segregated collection with direct recycle of newspaper, cans, and other potentially valuable materials is possible. Various types of resource recovery, discussed in a subsequent chapter, may affect the design or design capacity of the thermal processing facility.

Characteristics of Solid Waste

The design of a thermal processing facility will vary with varying waste characteristics. For example, where shredders are contemplated, the maximum size waste to be handled and the presence of hard-to-shred tramp metal is important. The moisture content is important in pyrolysis systems where driers are provided, and in incinerators where moisture content has a profound effect on the available heat for combustion. Effective resource recovery obviously depends upon knowledge of waste composition. As pointed out earlier, significant variations in waste composition do occur and must be accounted for.

FIGURE 2



Frequency diagram of cumulative weekly solid waste quantities delivered for disposal during a year. At the asterisk, 96 percent of the year (50 of 52 wks) the quantity of solid waste did not exceed 15 percent above the average yearly mean.

Not only has the per capita quantity of solid waste generated across the United States been increasing yearly, but the chemical and physical properties have been changing as well. As examples, the moisture content has been decreasing with a diminishing percentage of household garbage, the ash content decreased as less coal ash entered from households and elsewhere, and chlorine content has increased with increasing plastics consumption. Moreover, combustible content and heat value have been increasing, principally because of the ever larger use of both paper and plastics. The net result has been to increase heat value of the "as delivered" solid waste to such an extent that greater furnace volumes and more combustion air are required to maintain the rated burning capacity of an incinerator. This trend has positive implications with regard to heat recovery, and to potential yields from pyrolysis.

Composition of Urban Solid Waste. The composition of solid wastes varies widely (Tables 4 and 5), requiring estimates for the particular municipality involved. Projections show significant trends which will affect system designs (Table 6). Data on proximate analysis, ultimate analysis, and heats of combustion of individual components such as newspaper, cardboard, plastics, textiles, etc. have been published.[13,14] These can be used with component data to project overall analyses and heats of combustion.

The chemical analysis of solid waste is important to estimate air requirements and gas compositions for incinerators. For pyrolysis processes, the chemical analysis must be known to predict byproduct yields and compositions. The ash or inorganic content is an indicator of residue quantities and composition.

Sulfur, nitrogen, and chlorine analyses shown in Table 4, and other elemental analyses are useful in air pollution control considerations. The possible presence of toxic materials, for example, heavy metals such as beryllium, mercury and lead, pesticides, and asbestos should be considered, as should dangerous materials such as solvents.

The moisture content of solid waste is a particularly important variable because of its effect on available heat for combustion. Moisture content may also affect solid waste density and ease of handling. Good design practice requires the availability of minimum and maximum moisture values, as well as the average value.

Other Solid Waste Characteristics. Heats of combustion can be estimated from solid waste elemental analyses, but are preferably measured in standard bomb tests.[17, 18] Heat of combustion or "heat value" (calories per gram or BTU/lb.) is usually reported as the gross or higher heating value, although the net heat released in the incineration process is more nearly related to the net or lower value, which takes into account heat which is unavailable due to the release of water as a vapor, rather than as a liquid. Combustion heats are trending toward higher values (Table 6), tending to decrease the tonnage capacity of existing incinerators. Presorting, for example metal and glass removal, will tend to increase the heat of combustion of solid waste per unit of weight.

Table 4

RANGE IN COMPOSITION OF RESIDENTIAL SOLID WASTES IN 21 U.S. CITIES*

Component	Percent Composition by Net Weight		
	Low	High	Average
Food Waste	0.8	36.0	18.2
Garden Waste	0.3	33.3	7.9
Paper Products	13.0	62.0	43.8
Metals	6.6	14.5	9.1
Glass and Ceramics	3.7	23.2	9.0
Plastics, Rubber and Leather	1.6	5.8	3.0
Textiles	1.4	7.8	2.7
Wood	0.4	7.5	2.5
Rock, Dirt, Ash, etc.	0.2	12.5	3.7

* Unpublished data, Division of Technical Operations, Bureau of Solid Waste Management (currently U.S. Environmental Protection Agency, Office of Solid Waste Management Programs). Values were determined from data taken at 21 cities in continental United States between 1966 and 1969.

Table 5

ANALYSIS OF INCINERATOR SOLID WASTE*

Constituents	Percent by Weight (as-received)
Proximate analysis	
Moisture	15-35
Volatile matter	37-65
Fixed carbon	0.6-15
Noncombustibles	15-27
Ultimate analysis	
Moisture	15-35
Carbon	15-30
Oxygen	15-30
Hydrogen	2-5
Nitrogen	0.02-0.3
Chlorine	0.1-0.5
Noncombustibles	15-25

Higher heating value, calories per gram (as received)
1667-3333 (3,000-6,000 BTU/lb.)

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* Approximate ranges from reference 16, "Municipal-Scale Incinerator Design and Operation" (see reference 1 in Chapter 1) and other sources. Proximate and ultimate analyses by standard methods available from American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania.

Table 6

PROJECTED AVERAGE GENERATED SOLID WASTE COMPOSITION, HEATING VALUE, AND QUANTITY, 1970-2000[a]

Composition by type (weight %, as discarded):	1970	1975	1980	1990	2000
Paper	37.4	39.1	40.1	43.4	48.0
Yard Wastes	13.9	13.3	12.9	12.3	11.9
Food Wastes	20.0	17.8	16.1	14.0	12.1
Glass	9.0	9.9	10.2	9.5	8.1
Metal	8.4	8.6	8.9	8.6	7.1
Wood	3.1	2.7	2.4	2.0	1.6
Textiles	2.2	2.3	2.3	2.7	3.1
Leather and Rubber	1.2	1.2	1.2	1.2	1.3
Plastics	1.4	2.1	3.0	3.9	4.7
Miscellaneous	3.4	3.0	2.7	2.4	2.1
	100.	100.	100.	100.	100.
Overall Composition (weight %, as processed):					
Moisture	25.1	23.5	22.0	20.5	19.9
Volatile Carbon	19.6	20.1	20.6	21.8	23.4
Total Ash	22.7	23.4	23.9	22.8	20.1
Ash (excluding glass and metal)	6.5	6.2	6.1	6.0	6.0
Relative Heating Value and Quantity:*					
Heating Value (as fired)	1.00	1.02	1.04	1.09	1.17
Heating Value (dry basis)	1.00	1.00	1.00	1.06	1.09
National Population	1.00	1.05	1.10	1.31	1.51
Per-Capita Refuse Generation	1.00	1.13	1.26	1.44	1.66
Per-Capita Refuse Heat Content	1.00	1.15	1.31	1.57	1.94
Total Generated Refuse Quantity	1.00	1.19	1.38	1.89	2.51
Total Refuse Heat Content	1.00	1.23	1.44	2.05	2.93

* Ratio relative to 1970 value. Typical units for absolute values would be:

	Metric	(English)
Heating Value	Cal/g	(BTU/lb)
Per-Capita Refuse Generation	Kg/person per day	(lb/person/day)
Per-Capita Refuse Heat Content	Cal/person per day	(BTU/person/day)
Total Generated Refuse Quantity	Kg	(lb)
Total Refuse Heat Content	Cal or Kilocalories	(BTU)

The average heat of formation of solid waste can be predicted from the elemental composition of heat of combustion by conventional methods.[15] The heat of formation is useful in predicting heat requirements from pyrolysis reactors.

Bulk density data are required to design materials handling equipment and storage areas. As collected at the source in receptacles or piles, residential solid waste generally has a bulk density between 60 and 180 kilograms per cubic meter (100 to 300 lbs/CY). In the collection truck, solid waste is commonly compressed to 210 to 420 kilograms per cubic meter (354 to 707 lbs/CY). In the storage pit, the bulk density generally ranges from 180 to 330 kilograms per cubic meter (303 to 555 lbs/CY). Densities for storage in 8 to 11 meter deep pits have been estimated as a function of water content (Table 7).[14] Size reduction to 3 to 15 centimeters by shredding or pulverization may result in a waste of about 300 kilograms per cubic meter (506 lbs/CY), but this material is easily compacted to double that value.[19] Size reduction followed by separation of dense components such as metals, glass, and dirt may result in relatively low density material, well under 300 kilograms per cubic meter (506 lbs/CY).

The presence of bulky solid waste such as furniture, fixtures, appliances, and waste lumber present special problems in a solid waste processing operation. This subject will be treated in Chapter XVI.

Solid Waste Forecasts

There is no effective substitute for a careful solid waste survey and sampling to estimate current waste quantities and characteristics. However, predictive methods to produce data such as shown in Table 6 may be useful for estimating future wastes, including those generated by industry.[8-12] Predictive methods may be based on population, land use patterns, and industrial growth projections, all of which confirm the importance of the community and population data cited previously.

Byproduct Markets

An awareness of possible byproduct markets, particularly local markets, is an important element in planning and designing a thermal processing facility. Some of those that should be considered are:

- electrical power, especially non-peaking demands
- steam for heat, power, and air conditioning, especially non-peaking demands
- scrap iron, for example, for use as precipitant in copper production, or in iron and steel production
- glass cullet, either sorted by color or unsorted
- aluminum and other nonferrous metal scrap
- gaseous fuels (from pyrolysis)
- liquid fuels (from pyrolysis)
- carbonaceous fuels (from pyrolysis)
- ash and slag for concrete, land reclamation, road building, etc.

Table 7

MUNICIPAL REFUSE BULK DENSITY[14]

Moisture, %	Density, Kg/CM	(lb/CY)
10	154	(260)
20	181	(305)
30	225	(380)
40	273	(460)
50	344	(580)

- paper and cardboard for pulp, wallboard, packing, etc.
- tires and rubber for road materials and miscellaneous uses
- plastics for fillers, remelting, etc.
- wood for building board and miscellaneous uses.

The technology is not sufficiently advanced for economical recovery of some of these materials, but present research activity in resource and energy recovery, coupled with changing market conditions, requires a constant awareness of the possibilities. Further discussion of markets for recovered energy and materials may be found in Chapters X and XVII.

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CHAPTER III

THERMAL PROCESSING COSTS

As for any other process plant, thermal processing costs consist of those required to:

1. Acquire the necessary facilities (capital costs),
2. Own the plant (amortization and interest on capital costs), and
3. Operate the facilities (labor, utilities, supplies, maintenance, overheads).

With the surgent interest in energy and resource recovery, another major cost dimension has been added. The recovery of "byproducts" from solid waste disposal normally increases costs for all three of the above, but sales revenues from byproducts can also provide credits against operating costs.

Other financing arrangements which are sometimes advantageous and feasible, such as private ownership and operation, will not be dealt with in this publication. Provisions for working capital and depreciation may also be considered, depending on cost management procedures used by a particular municipality.

Accurate pre-construction and post-construction cost data are essential for planning; for funding decisions; for municipal budgets and accountability; to aid in decision-making for plant modifications; to set solid waste disposal prices for private or public parties not involved in ownership; and to negotiate byproduct prices, for example, for steam from energy recovery incinerators, fuels from pyrolysis facilities, and for glass, metals, and other resources recovered from a variety of thermal processing facilities. A useful accounting procedure for incineration operations is available.[1]

It cannot be emphasized enough that the data presented herein are meant for orientation and illustration only. Even for planning purposes, study cost estimates prepared by qualified design and construction firms for specific facilities must be obtained. The recent very rapid rate of inflation, changing technology, increasingly stringent environmental and worker health and safety requirements, and other such factors, may make generalized cost data almost immediately obsolete.

Capital Costs for Refractory Incinerators

Capital costs necessary to acquire refractory incinerator facilities can be broken down as follows:

- pre-operating expenses such as legal, financial, and consulting fees, and interest on construction loans
- land acquisition and site preparation, including fences, roads, and parking lots

- engineering, project management, construction expenses, and contractors' fees
- buildings and foundations
- refuse weighing, handling, preparation, and storage systems
- furnaces and appurtenances
- fans, pumps, and motors
- residue removal systems
- air pollution control systems, including stack(s)
- water pollution control systems
- utility generation and distribution
- instrumentation, controls, and laboratory
- piping and duct work
- locker rooms, offices, and sanitary facilities
- start-up costs, including acceptance tests

Each of these cost elements is significant and requires careful consideration, as discussed elsewhere in this publication. When budgeting capital costs, a contingency should also be included. The contingency is a judgment factor which may range from as little as 5 percent, based on estimates for completely designed systems, to as much as 20 to 30 percent for systems in the planning stage which involve incompletely developed technology.

A 1969 study[2] developed capital cost ranges for batch and continuous feed incinerators. As shown in Figures 1 and 2, these costs are grossly broken down into furnace, building, and electrostatic precipitator costs, including most of the above items but not pre-operating expenses, land acquisition and site preparation, or project management.

The costs shown in Figures 3 and 4 can be corrected to the year in question using Marshall & Swift (M&S) Indexes[3] (annual average) which follow:

1968	273.1	1972	332.0
1969	285.0	1973	344.1
1970	303.3	1974	398.4
1971	321.3	1975	444.3

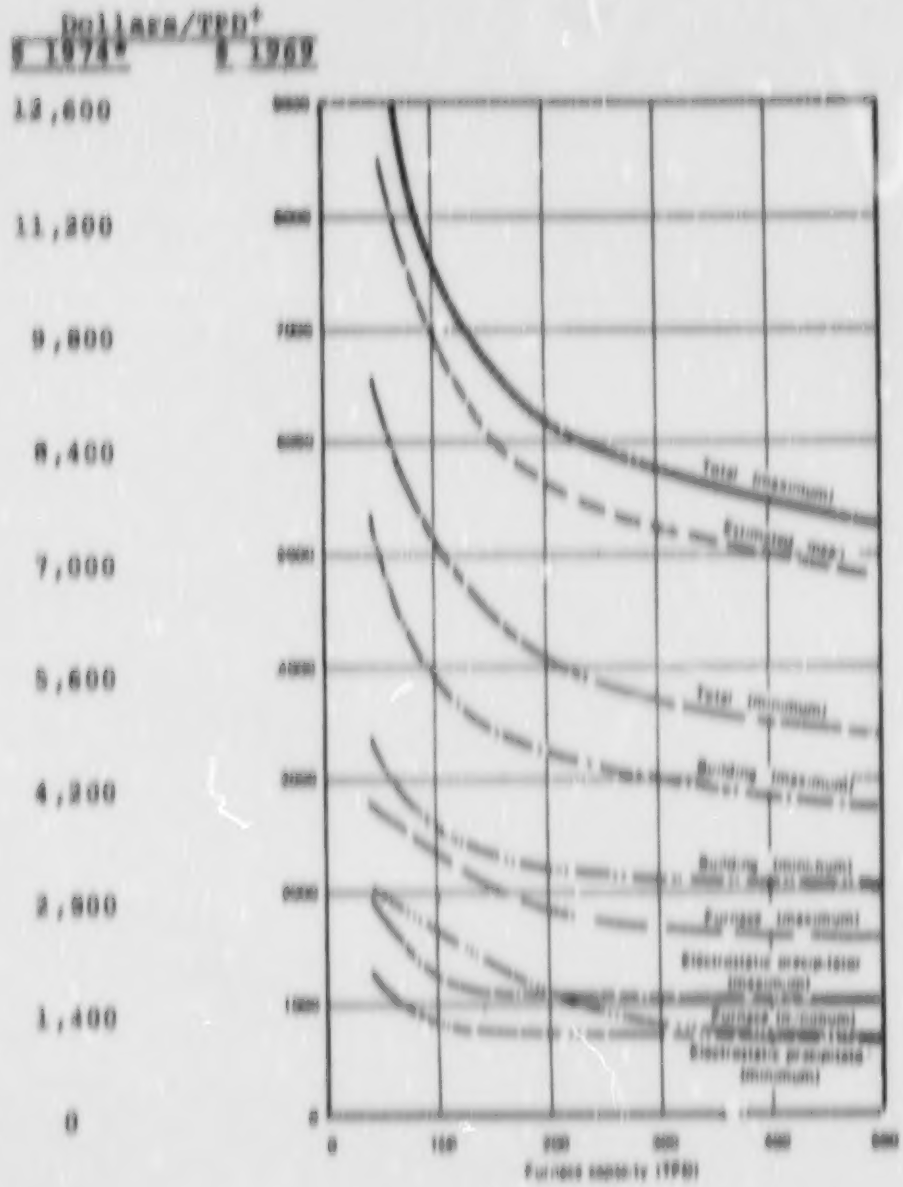
Capital costs for eight incinerators built before 1968, obtained from the literature[4] and other sources, corrected by use of M&S Indexes and plotted on Figure 4, agree well with the curves for total investment. However, the wide range of possible costs,[2, 4] recent more stringent standards, as well as previously noted uncertainties, point up the need for careful cost estimation, and cost-benefit analyses for discretionary design factors.

Capital Costs for Steam Generating Incinerators

Steam generation, using municipal solid waste as fuel, is receiving an unprecedented surge of interest in the U.S., with no fewer than twenty cities planning, building, or operating facilities to produce steam in specially designed incinerators, or to burn prepared refuse in fossil-fuel fired boilers.

As compared to refractory furnaces, costs for the following items must be added for steam generating incinerators:

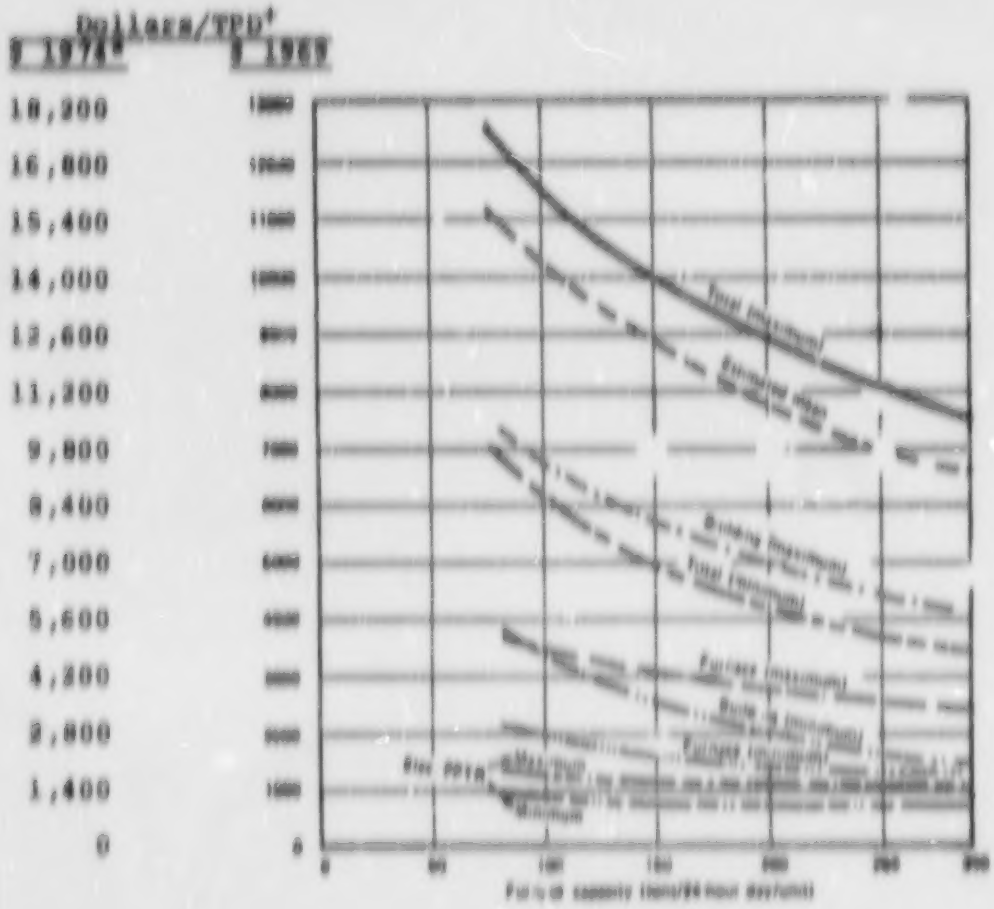
FIGURE 3. CAPITAL COSTS FOR REFRACTORY BATCH FED INCINERATORS



*M&S factor 1969:1974 = 1.40

†TPD = short tons (2000 lbs) per day
TPD x 0.0378 = metric tons per hour

FIGURE 4. CAPITAL COSTS FOR REFRACTORY CONTINUOUS FED INCINERATORS[7]



*M&S factor 1969-1974 = 1.40[7]
†TPD = short tons (2000 lbs) per day
TPD x 0.0378 = metric tons per hour

- waterwall furnaces (replacing refractory furnaces)
- waste heat boilers, high pressure steam piping, soot blowers, and other appurtenances
- turbine drives for inplant steam use where feasible
- boiler feedwater and condensate treatment systems
- excess steam condensers
- complete auxiliary boilers and/or burners
- boiler controls and instrumentation

Although the use of waterwall steam generating boilers reduces gas flow and therefore the cost of the gas handling equipment (e.g., fans, air pollution control equipment, stack(s)), the above noted cost elements more than offset these reductions, increasing overall capital cost. With present day fuel prices, the increased capital cost can be justified by steam sales where a market exists.

Referring to Figure 5, a reproduction of the 1969 study data[2] on steam generating incinerators, the estimated 1974 cost can be compared with a refractory continuous fed incinerator from Figure 4, as shown in Table 8.

In Table 9, actual cost data for three steam generating incinerators built were adjusted to 1974 and compared to the 1969 cost curves by plotting the data in Figure 5. In this case, the capital costs for these recent incinerators exceeded values predicted by the curves. This is most likely due to more stringent design standards, especially with regard to air pollution control equipment.

When the municipality is responsible for steam distribution, an additional major capital cost may be incurred, depending on distance and steam pressure. If the steam is converted to another form of energy, such as chilled water or electric power, major capital costs are also required for energy conversion facilities and distribution. An example of such costs is provided in Table 10.

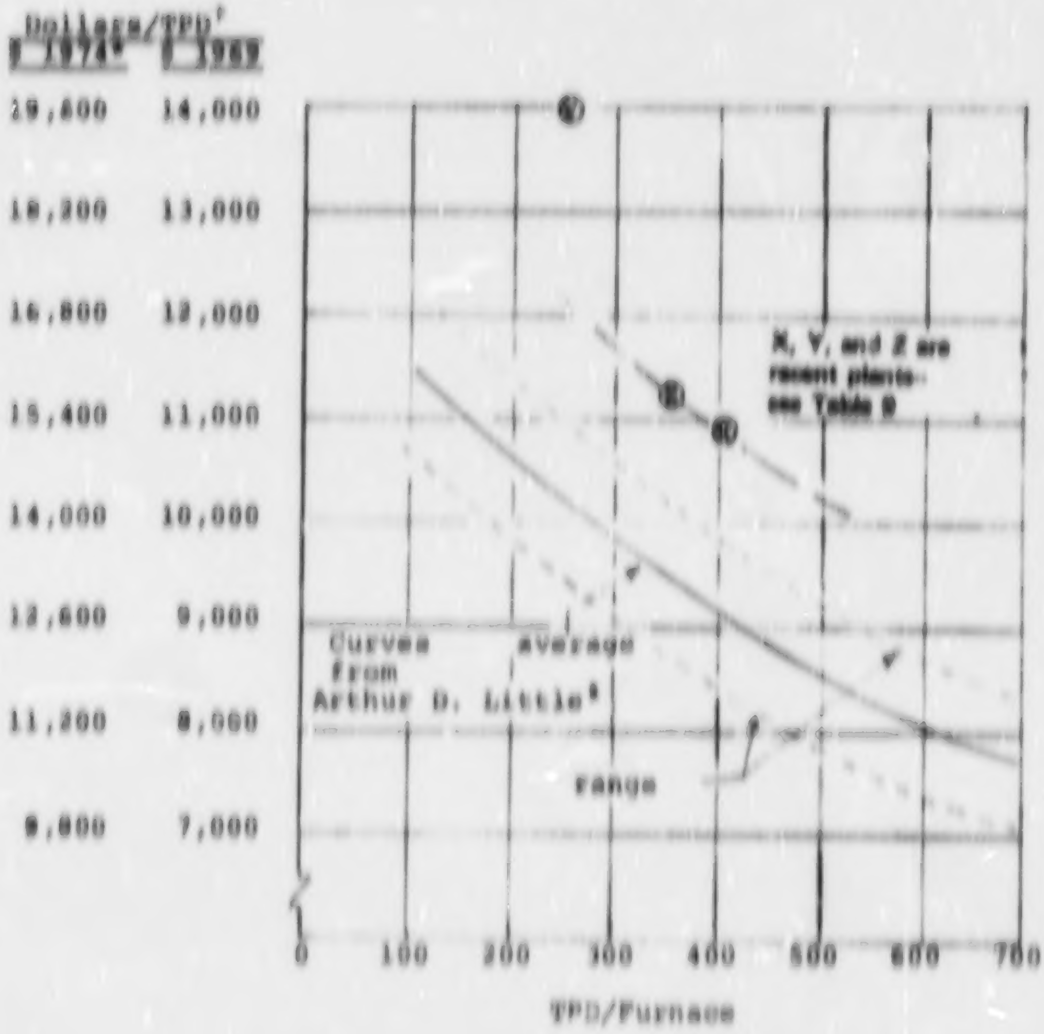
The major capital costs for a steam generating incinerator are for furnaces, steam boiler equipment, residue handling, air handling, and air pollution control. Together these comprised over 70 percent of the total cost for a recent installation, as shown in Table 11.

Capital Costs for Other Types of Thermal Processing Units

Since pyrolysis facilities are only now approaching commercialization, no historical cost data are available. It is reported that the Baltimore 37.8 metric ton per hour (1000 short tons/day) facility, using the Monsanto Landgard process, has cost $16 million.

The prototype fossil fuel/prepared refuse combustion (co-combustion) project was reported to have cost $3.5 million, including $2.95 million for a 12.3 metric ton per hour (325 short ton/day) refuse preparation system and 0.55 million for receiving and handling facilities at the existing power plant.

FIGURE 5. CAPITAL COSTS FOR STEAM GENERATING INCINERATORS (EXCLUDING STEAM DISTRIBUTION)



*M&S factor 1969→1974 = 1.40³
†TPD = short tons (2000 lbs.) per day
TPD x 0.0378 = metric tons per hour

Table 8

MEAN 1974 COST PER TON OF CAPACITY AT 11.3 MT/HR (300 TPD) CAPACITY*

Refractory incinerator (from Figure 2, maximum)	$280,000 per MT/hr	($10,600/TPD)
Steam generating incinerator (from Figure 3, high end of range)	$392,000 per MT/hr	($14,800/TPD)

* 1 MT/hr = 1 metric ton per hour = 2205 lbs/hr
1 TPD = 1 short ton per day = 2000 lbs/day
Excluding energy distribution or conversion system costs

Table 9

ACTUAL COSTS FOR THREE STEAM GENERATING INCINERATORS*

Site	X	Y	Z
Capacity, TPD	4 x 400	4 x 250	2 x 360
Actual Cost, $MM	17.4	16.8	9.8
Year	1969	1973	1973
M&S Cost Factor	1.40	1.16	1.16
1974 Cost, $MM	24.4	19.5	11.4
1974 Cost, $/TPD	15,300	19,500	15,800
$ per MT/hr	403,000	516,000	419,000

* TPD = ST/day

Table 10

ACTUAL COSTS OF ENERGY DISTRIBUTION AND CONVERSION SYSTEMS*

Site	Y	Z
Year	1973	1973
Refuse Capacity, TPD	4 x 250	2 x 360
Distribution System	steam	steam, chilled water
Distribution System Cost	$2.2 MM	$4.0 MM
Energy Conversion System	none	steam-chilled water
Energy Conversion System Cost	**	$3.0 MM

* TPD = ST/day

Table 11

CAPITAL COST BREAKDOWN FOR A STEAM GENERATING INCINERATOR*

	%
Furnaces, boilers, precipitators, ID fans, ash conveyors, ash crane	70.7
Building, foundations and concrete works	7.4
Building, steel structure	2.2
Building, general construction	4.7
Refuse cranes	2.5
Chimney and flyash silo	1.4
Conveyor system for flyash	1.1
Pumps and steam turbine	0.6
Emergency steam condenser	1.5
Electronic weighing scales	0.5
Water treatment plant	1.0
Central control panel and instrumentation	0.5
Other plant utility equipment and systems (fuel oil, air, steam, electrical)	1.5
Access ramps, water and sewer	2.4
Landscaping and site works	1.2
Temporary services during construction	0.8
	100.0

*Derived from reference 5. Excludes land cost, engineering, contingencies, and steam transmission.

Recent cost projections have been made for 37.8 MT/hr (100 ST/day) co-combustion and PUROX pyrolysis systems:[6]

	$ per MT/hr	$ per ST/day
Co-combustion	251,000-291,000	9,500-11,000
PUROX	627,000-693,000	23,700-26,200

The co-combustion process produces a refuse-derived-fuel and salvage materials; while the PUROX process, currently being tested in a large pilot plant, produces a clean fuel gas and fused frit, with the option of materials recovery instead of frit.

Operating Costs

The operating cost for thermal processing facilities as used in this publication, is the expense involved in keeping the facility running to dispose of solid waste and to recover products of value, when the latter is an integral part of the operations. Operating costs are usually broken down into direct (or variable) costs and indirect (or fixed costs), although some costs are semi-variable.

Direct costs, such as utilities and residue disposal, tend to be proportional to solid waste throughput. Indirect costs, such as insurance and facility protection, tend to be independent of throughput. When projecting or otherwise analyzing costs, it is necessary to carefully determine which costs for the specific facility in question are indirect or direct. For example, although operating labor is normally considered a direct cost, operation of a thermal processing facility with municipal employees may require the maintenance of a fixed size labor force over a long period of time, regardless of throughput. Thus, normal wages for such a labor force become an indirect cost, independent of throughput.

Direct Labor and Labor Overhead Costs. As shown in Table 12, labor and labor overheads comprise the largest single operating cost.

Labor usually represents the largest single operating cost. Unit labor costs ($/ton) are obviously a function of wage rates and the number of personnel required, but also depend upon actual vs design throughput where the total number of personnel is rather inflexible. Wage rates usually are fixed by prevailing scales paid to comparable municipal employees. However, higher wage scales competitive with local industry, where different than municipal scales, may attract personnel of greater experience, training, and responsibility.

Since increasing facility size does not proportionately increase personnel requirements, large facilities show smaller unit labor costs than small ones. For example, although three incinerator operators per shift may be required for three 400 ton per day incinerator trains, four similar size trains may also require only three operators, a reduction of 25 percent in unit cost for capacity operation.

Table 12

EXAMPLE OF OPERATING COST CALCULATION FOR INCINERATOR OPERATING AT DESIGN CAPACITY

Basis:
1. 16 MT/hr average output, 24 hrs/day, 365 days/yr
2. 50 KWH/MT electric power @ 4¢/KWH
3. 5 MT/MT cooling water @ 2.5¢/MT
4. Direct labor, 50 men @ $13,000/yr average wage
5. Labor overheads at 30% of direct labor
6. Contract maintenance and materials, and supplies, @ $150,000/yr
7. Indirect costs at 40% of direct labor

Operating Costs,* $/MT

Direct	
Labor	$ 4.64
Labor Overheads	1.39
Utilities	2.13
Maintenance	1.07
	9.23
Indirect	1.86
	$ 11.09

*Excludes ownership costs

Labor requirements are also determined by the degree of instrumentation, automatic control, and other labor saving devices. Similarly, added capital investment for spares, high quality equipment components, and other methods for improving reliability can also reduce unit labor costs, but each such added investment should be carefully justified, using actual operating data where possible.

Overheads which are directly related to labor requirements, for example, payroll taxes and benefits such as retirement and health plans, vacation, sick leave, etc., are termed labor overheads. These vary with location but are usually identical to those used for other municipal employees, except where special benefits such as safety shoes, safety glasses and hardhats are supplied by the incinerator management.

When calculating labor costs, provisions must be made for overtime pay, shift differentials, and other costs associated with continuuusly manning an operating facility.

Utility and Direct Supply Costs. Utility and supply requirements and costs for individual incinerators may differ markedly. Some of the factors which affect these costs are shown in Table 13.

The major utilities normally required in incinerators are electric power for motors and lighting, fuel for space heating and auxiliary steam production, and water for cooling, quenching, drinking, steam generation, and sanitary facilities. More than one type of water may be used, for example municipal water for drinking and river water or seawater for residue quenching. Direct supplies used in incinerators may include chemicals for water treating, charts and other supplies for instruments, janitorial supplies, deodorants, personal safety equipment, uniforms, and a myriad of other small items. Usually excluded from this category are materials used in repair and maintenance.

When prices do not vary substantially with the quantity used, utility and supply costs may be considered direct, these costs being dependent on throughput. The estimate of utility costs for new incinerators should be based on local projected rates and on sound engineering estimates of the quantities required. Supply costs are normally much less significant than utility costs.

Maintenance Costs. The two major components of maintenance costs are materials and labor used for repairs and routine maintenance, although where contract maintenance is practiced this may be considered as a separate category. The maintenance of instrumentation, cranes, weighing scales, and other complex equipment by outside contractors should be considered because it is difficult to find all necessary skills in the relatively small maintenance crews available at most incinerators. Centralized maintenance for all public works is used in some municipalities.

Maintenance costs vary greatly with adequacy of the incinerator design, age of the facility, quality of equipment, skill of the operators, and nature of the solid waste. For example, replacement of refractory, a major cost in in most incinerators, is dependent on all these variables, with minimal costs incurred where high quality refractory is used and where automatic temperature control is reliable.

Table 13

MAJOR FACTORS AFFECTING INCINERATOR UTILITY COSTS

Factor	Comments
Local utility price structure	Prices for purchased utilities such as electric power and water vary greatly between localities, due to differences in availability of fuels for power generation, and of natural water supplies.
Excess air requirements	Power requirements increase as excess air increases, both for forced draft fans and for induced draft fans. Steam generating incinerators with waterwalls use less excess air.
Type of air pollution control	High energy scrubbers for particulate control have high draft requirements, provided by fans which consume much more power than is necessary for the combined requirements of electrostatic precipitators and fans for that type of system.
Internal generation of steam	A major portion of required power can be supplied by internally generated steam. Chemicals are required for boiler feedwater treating.
Residue and wastewater systems	Makeup-water requirements can be minimized by reusing wastewater from scrubbers and spray coolers to handle solid residues, and by effective wastewater treatment systems which allow maximum water recycle.
Solid Waste composition	Increased waste moisture in refractory incinerators can decrease excess air required for cooling, but too high a moisture content can necessitate auxiliary fuel burning, especially in steam generating incinerators. Acidic precursors in waste, such as polyvinylchloride plastics, affect requirements for neutralizing chemicals in wastewaters.

Scheduled inspection and maintenance programs help to hold down the extraordinary cost sometimes associated with unexpected equipment breakdown and sudden loss of incineration capability. Total maintenance costs can be expected to lie in the range of 1 to 5 percent of the original investment per year, although costs may be expected to increase with the age of the facility faster than escalation, and vary greatly from year to year.

Other Overhead Costs. Overhead costs, other than labor overheads previously discussed, are those costs that are necessary but not easily connected directly with the operation of the facility. They are, in fact, indirect or fixed costs incurred whether or not the incinerator is operating. These may include management, accounting, engineering, secretarial and clerical personnel and costs, insurance, laboratory expenses, training, travel, and other costs. The distinction between overheads and direct costs is not always clear, but should be made as consistently as possible. Depending on accounting methods and the distinctions made, overhead costs may run, for example, from 30 percent to 60 percent of direct labor.

Ownership Costs for Incinerators

Ownership costs may be described as those costs which accrue whether the facility operates or not, temporarily or permanently. The ownership costs for municipal thermal processing facilities are interest payments on borrowed capital and the return of that capital. If money is actually set aside periodically for the purpose of returning borrowed capital at a future date, for example as prescribed in bonds issued to lenders, the process is called amortization. If the original capital used to build a facility comes from general tax revenues, a yearly depreciation expense should be charged, which allows for the decrease in the value of the facility due to wear and tear and obsolescence, recognizing the need for future capital to replace the existing facility.

Where bond terms are such that interest is paid periodically and an actual amortization sinking fund is established to repay the loan on a certain future date, annual ownership costs are the annual interest cost plus the annual amortization payment to the sinking fund, less interest earned by the sinking fund. Even where no actual sinking fund exists, costs may be calculated in this way. In any case, ownership costs should be calculated in such a way as to be consistent with the terms of securities sold to raise the necessary capital.

When depreciation expense instead of amortization is used to analyze thermal processing ownership costs, the normal practice is to uniformly distribute the total capital cost by annual charges over a period of about 20 to 30 years, depending on the predicted life of the facility, or to depreciate plant components over periods which range from about 4 to 30 years depending on expected life. More complex depreciation approaches which recognize greater depreciation in early years (accelerated depreciation) are often used in industry, especially for tax advantages, but find little application in thermal processing facilities.

Interest charges will be determined by free market rates and the credit rating of the municipality when bonds are sold. Since the interest on municipal bonds is received tax-exempt by the owner of the bonds, the rates are significantly lower than comparably rated industrial bonds. A typical ownership cost calculation is provided in Table 14. Because of the great significance of ownership costs, more than the usual care should be taken in calculating these, and in being explicit about the calculation basis.

Since ownership costs are obviously directly related to the size of the capital investment, increased investment for greater reliability of lower labor, utility, or maintenance costs will correspondingly increase the cost of ownership. Therefore, careful cost-benefit analysis is required to determine the optimum investment/operating cost relationship for the specific project being contemplated.

Underutilization dramatically increases the magnitude of indirect and unit ownership costs ($/ton), since these costs go on even if the facility never operates. For example, Table 15 shows the increase in total unit costs for an existing incinerator operating on different schedules and throughputs. Unit costs of $14.94/MT for a 7 day three-shift operation increase to $33.23/MT for a 5 day one-shift operation, due to the effect of fixed costs. Obviously, oversizing an incinerator, or underutilization, can result in an extraordinary cost for refuse disposal.

Economics of Energy and Resource Recovery

Energy may be recovered from thermal processing systems in the form of steam, fuels, or electrical power, as shown in Tables 16 and 17. Part of the energy recovered may be used internally, but most is available for export. Other resources, such as glass, ferrous scrap, aluminum, and other metals, can be recovered prior to or after thermal processing. Combustible resources such as paper fiber may also be recovered, but are not normally done so as a part of a thermal processing system.

The value of energy and recovered resources can have a major impact on net thermal processing costs, and can theoretically even pay for the entire cost of thermal processing. The following discussion is designed to show the potential promise for energy and resource recovery, but the management of thermal processing facilities must overcome the institutional, technical, and marketing problems inherent in realizing this promise.

Table 17 clearly shows the potential for recovery, and the effect of price structure on this potential.

The recovery of glass and metals is of definite interest as a method of offsetting thermal processing costs, but it is the recovery of energy in an environment of rising energy prices that shows really major potential for beneficial use of municipal solid waste.

However, it is insufficient simply to know the value of resource and energy recovery, the cost of such recovery must also be thoroughly evaluated.

Table 14

TYPICAL OWNERSHIP COST CALCULATION

Basis:
1. Capital Cost (per unit of capacity) = Capital Borrowed = $397,000 per metric ton/hr ($15,000 per TPD)
2. Bond Interest Rate = 7%/yr
3. Repayment of bond after 30 years
4. 30 year life for incinerator (no salvage value)
5. Sinking fund interest = 5%/yr
6. Operation at 100% of capacity

	Ownership Cost $/metric ton
Yearly Interest @ 7%/yr	$ 3.17
Uniform Annual Amortization Payment*	0.68
Total Ownership Cost	$ 3.85

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* If this payment is made annually for 30 years to a sinking fund earning 5% interest compounded annually, the sinking fund balance at the end of the 30 years will be equal to the original capital borrowed.

Table 15

ECONOMIC EFFECT OF UNDERUTILIZATION OF INCINERATOR FACILITIES*

Operating Schedule	7 day - 3 shift	5 day - 2 shift	5 day - 1 shift
Operating Rate, % of Capacity	100	47.6	23.8
Design Capacity, MT/hr (ST/day)	16 (425)		
Operating Rate, MT/yr	140,000	66,640	33,320
Operating Costs, $/MT			
Direct	9.23	9.23	9.23
Indirect	1.86	3.91	7.82
Ownership	3.85	8.09	16.18
	$14.94	$21.23	$33.23

* This table does not account for underutilization attributed to maintenance or downtime, which can be as high as [illegible]0% per day.

Table 16

ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE THERMAL PROCESSES

Type of Thermal Processing	Form of Energy Recovery* (based on refuse as delivered)
Refractory Incineration With or Without Waste Heat Boilers	0-1.5 tons steam/ton refuse (or electric power generated from steam)
Modern Waterwall Incinerators	1.5-4 tons steam/ton refuse (or electric power generated from steam)
Combined Fossil Fuel/Refuse Combustion Boilers	1.5-4 tons steam/ton refuse (or electric power generated from steam, e.g., 500-800 KWH per metric ton of refuse)
Pyrolysis Plants	Gaseous, liquid, or solid fuels (or steam or power generated from fuels)
High Pressure Fluidized Bed (Under development)	400-500 KWH electrical power per metric ton of refuse

* Quantitative values for recovered energy derived from reference 7 and other sources.

Table 17

RANGE OF POTENTIAL VALUES FOR RESOURCE RECOVERY IN THERMAL PROCESSING FACILITIES

Resource	Recoverable Units per Metric Ton of Mixed Waste	Realized Value FOB Plant, $/Unit			Value, $ per Metric Ton of Mixed Waste		
		A**	B	C	A**	B	C
1. Glass	0.05 MT*	5	20	50	0.25	1.00	2.50
2. Ferrous Metal (feed)	0.06 MT	5	20	50	0.30	1.25	3.00
3. Ferrous Metal (residue)+	0.04 MT	5	20	50	0.20	0.80	2.00
4. Nonferrous Metal	0.004 MT	150	250	400	0.60	1.00	1.60
5. Steam	3.3 MT	1.00	2.00	4.00	3.30	6.60	13.20
6. Electrical Power	450 KWH 600 KWH	0.008 0.008	0.02 0.02	0.03 0.03	3.60 4.80	9.00 12.00	13.50 18.00
7. Fuel# ($/$10^6$ BTU)	0.24 MT	10 (0.43)	25 (1.08)	40 (1.73)	2.40	6.00	9.60

* MT = metric ton = 2205 lbs.
+ Incinerator residue
# Pyrolysis liquid at 5.834 x 10^6 kcal/MT fuel (10,500 BTU/lb)
** A, B, & C are example sites

As shown in Table 18, the cost of separation steps, required prior to thermal processing for resource recovery, are substantial.

The overall cost of recovery must be estimated with great care for each facility under consideration. However, for purposes of orientation only, a hypothetical study is provided in Table 19.

It is obvious from the information in Table 19 that the critical aspect of an economically attractive project for thermal processing with resource recovery is locating and assuring markets for the recovered energy and materials. The size of the project is also a critical factor.[8]

One recent set of cost estimates (1974) made for projects producing refuse-derived-fuel, pyrolysis gas, pyrolysis liquid, steam from incineration, and other forms of energy are much higher than those discussed here, but insufficient detail is provided to evaluate this information.[9] A more detailed set of estimated costs for dry-shredded-fuel processing plants has been prepared by the U.S. Environmental Protection Agency,[10] showing the effect of estimated revenue ranges, capacity utilization, and special costs such as taxes, transportation, high residue disposal charges, unusual site work, etc. These cost data show that such a project can range from profitable to a high cost of solid waste disposal, depending on the specific project conditions encountered.

Projected economics for two recent thermal processing facilities, summarized in Table 20, show that economically attractive projects are possible. Since both projects are still in their startup phase, these results have yet to be verified.

Table 16

FRONT END SEPARATION PROCESSES INCREMENTAL CAPITAL AND OPERATING COSTS[6]

Basis: 331,000 MT/yr Plant, 365 day/yr operation

Unit Operation*	Capital Cost† $/MT/hr ($/ST/day)	Ownership Cost# $/MT	Operating Cost $/MT	Total $/MT
Primary shredding	33,070 (1250)	0.41	2.78	3.19
Air Classification	25,100 (950)	0.31	1.50	1.81
Secondary shredding	16,500 (625)	0.20	1.76	1.96
Magnetic metal separation	2,000 (75)	0.02	0.43	0.45
Rising current/ heavy media separation	6,900 (260)	0.08	0.45	0.53
Roll crushing & electrostatic separation	7,100 (280)	0.09	0.49	0.58
Color sorting	11,200 (425)	0.14	0.44	0.58

* Those listed are not all fully proven in large scale operation
† Does not include land or buildings
# 15 year amortization, 7%/yr interest

Table 19

ECONOMIC POTENTIAL FOR THERMAL PROCESSING FACILITIES WITH RESOURCE AND ENERGY RECOVERY

	Ownership and Operating Costs $/MT*	Resource Recovery†	Resource Credits, $/MT†	Net Cost (Profit), $/MT
Incineration Only	8.47	None	-	8.47
Incineration and Residue Recovery	9.88	Ferrous & Nonferrous Metals, Glass (1,3,4)	1.05-6.10	3.78-8.83
Incineration and Steam Generation	11.44	Steam (5)	3.30-13.20	(1.76)-8.14
Incineration With Steam Generation and Residue Recovery	12.89	Ferrous & Nonferrous Metal, Glass, Steam (1,3,4,5)	4.35-19.30	(6.41)-8.54
Pyrolysis with Resource and Oil Recovery	12.08	Ferrous & Nonferrous Metals, Glass, Oil (1,2,4,7)	3.55-16.70	(4.62)-8.53

* For 272,000 metric ton (MT) per year facility; derived from a 1973 report to the President's Council on Environmental Quality.[8] To be used for orientation only.

† Numbers under "Resource Recovery" heading refer to items on Table 17.

Table 20

PROJECTED ECONOMICS FOR RECENT ENERGY RECOVERY PROJECTS

Type of Project and Capacity	Incinerator With Steam Generation[*] 4 x 227 MT/day	Pyrolysis 907 MT/day[†]	
Steam Price $/MT steam	$2.09	$ 1.79[†]	$ 4.83[†]
Operating Costs, $/MT	$3.40	6.46	6.46
Ownership Costs, $/MT	6.00	4.10	4.10
Total Costs, $/MT	$9.40	$10.56	$10.56
Credits from Sale of Steam, $/MT	6.28	4.29	11.59
Net Cost (Profit), $/MT of Waste Processed	$3.12	$ 6.27	($ 1.03)

[*] Original projected economics for 1980. Steam price to vary by formula as Bunker C price varies.

[†] Projected economics for 1975. $1.79/MT steam (81¢/1000 lbs) based on $3.70/barrel No. 6 fuel oil. Escalation in sales contract of $0.002189/1000 lbs steam per 1¢ change in fuel oil price to $4.83/MT ($2.19/1000 lbs) for $10/barrel No. 6 fuel oil.

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CHAPTER IV

SITE SELECTION

The major factors to be considered in selecting a site for an industrial plant are:

1. raw materials sources
2. transportation facilities
3. waste disposal
4. suitable land
5. utilities
6. markets
7. environmental, zoning, and other regulations
8. public acceptance
9. labor
10. taxes
11. building costs
12. availability of repair and other labor services
13. climate

Many of these same considerations must be applied to a thermal processing facility for municipal wastes. However, factors 9 thru 13 cannot be easily controlled or do not apply directly to site selection for local or even regional governmentally owned solid waste processing facilities. These will not be considered further here.

Raw Material Sources and Alternative Disposal Plans

Obviously, the raw materials under consideration are the solid wastes, but these may be transported from a wide area or a limited area depending upon the nature of the community, and on the regionalization of the collection system. A central location to minimize transport time may be an important consideration in large regional systems, and collection economics versus site should be studied. Transfer stations should also be considered, especially where pre-shredding and resource recovery is to be practiced.

One major consideration for thermal processing site selection, that usually does not exist for industrial process units, is the planning necessary for facility downtime. For municipalities or regions with a single processing facility, sanitary landfill sites are usually the only practical answer, with a landfill site used for residue disposal being most convenient. If a processing site is adjacent to or near the landfill site, normal or nearly normal collection and traffic patterns can be maintained.

The acceptability of commercial, industrial, and bulky wastes may also be a significant consideration. The commercial and industrial wastes can have a major effect on traffic patterns. When bulky wastes which are to be landfilled are collected with other wastes, the presence of a nearby landfill site is especially advantageous.

Transportation Facilities

Since solid wastes ordinarily enter the plant by truck, the surrounding road facilities are critical. If major road changes must be made to utilize a particular site, the cost should be considered to be a part of the cost of that particular site. Peak rather than average traffic loads should be considered, since most collection schemes envision a single starting time for all crews leading to peak unloading hours.

Waste Disposal

Ordinary incinerators result in three solid waste products which may or may not be combined before leaving the plant: grate sifting; combustion residue; and flyash. These wastes, and bulky wastes, are the factors which enhance the desirability of having landfill and incinerator sites adjacent to each other. Regardless of the location of the landfill site, it must meet sanitary landfill criteria.[1] Transport of wastes to distant sites is a nuisance, (e.g. dry flyash recovered from electrostatic precipitator hoppers presents dust problems; transport of wet residues may present water runoff problems) and may be expensive, e.g. $1 to 3 ton. Recovery of ferrous metals, and possibly other resources, from residues eases the disposal problem and may produce some profit, as discussed in Chapter XVII.

Water is usually used for residue recovery and often for spray chambers and scrubbers. Recycle and neutralization should be practiced to the greatest extent possible, but purge water is too high in solids, BOD, and temperature for discharge to freshwaters. Therefore, the presence of sanitary sewers can be an important site consideration to minimize on-site water treatment, but the availability of sufficient sewage treatment plant capacity must be assured.

In selecting a site, it is also necessary to have data on the movement of ground waters and runoff water, and to provide design conditions which will avoid water pollution problems.

Suitable Land

Only rarely will suitable sites be found available in areas which have not already been industrialized. The availability of already assembled land sites in industrial areas eases the site selection problem. Existing landfill sites are a favorite choice, but unfortunately many existing landfill sites have been poorly chosen, e.g. in marshy areas. Existing landfill areas must be carefully checked for foundation conditions, uncontrolled leaching, gas generation, and possible flooding conditions.

If possible, it is desirable to avoid land areas near schools, hospitals, and other institutions. Adjacent highways should also be avoided, especially when scrubbers are used for air pollution control. The saturated flue gases can be a highway hazard, especially under low temperature conditions which result in artificial fogs or even highway surface freezing.

Topography is another important land consideration. A flat site is apt to require a ramp to the tipping floor, whereas a hillside site can provide access at various ground levels. Topography also affects the dispersion of flue gases and should be considered in meteorological calculations.

In many cases, a site should be chosen which is suitable for expansion.

Utilities

Electrical power, fresh water, and fuel are required for almost any thermal processing facility. These will be discussed further in Chapter VI, "Utilities." The availability of electrical power and fresh water facilities may sometimes affect site selection. Natural gas or oil used as auxiliary or startup fuel is interchangeable from a design point of view and is required in relative small quantities, so that fuel availability will seldom significantly affect site selection.

Markets

Markets for steam made in waterwall incinerators may have a very significant effect on site selection. Long distance transport of steam is uneconomical because of piping costs, heat loss, and the simultaneously increasing cost of condensate return. The costs of electrical distribution in relatively small quantities is also expensive unless existing networks can be used.

Markets for possible resource recovery products, such as ferrous metals, glass, aluminum, copper, and zinc have relatively little effect on thermal processing site selection, although market availability may have a profound effect on the economic decision of whether recovery is worthwhile.

Oil and coke made in pyrolysis processes do have significant effects on site selection, particularly with regard to the necessity for storage tanks and areas. Pyrolysis processes that produce primarily combustible gases for export affect site selection much more because of the high cost of storing and transporting combustible gases, or of the steam which can be made from the gases.

Environmental, Zoning, and Other Regulations

Reference to local, State, and Federal regulations and master plans aid in the early elimination of potential sites. It may be very difficult, or almost impossible, to gain acceptance of sites which seriously conflict with existing codes.

As discussed in Chapter II, EPA's "Guidelines for Thermal Processing" and "Standard of Performance for New Stationary Sources" govern the construction of new facilities. In addition, Federal, State and local air and water quality standards must not be exceeded. For example, it may be necessary to show by meteorological calculations for a certain site that air quality standards are met over the entire area affected.

Zoning regulations can be modified to allow thermal processing unit construction where not already contemplated, but the inertia against such modification is often formidable. Where plans can be formulated for regional approaches to solid waste management, including multiple thermal processing units, public acceptance, as discussed in the following section, may be easier to gain.

Public Acceptance

The most important factors in gaining public acceptance for a thermal processing facility site are:

1. The inherent logic of the site selection as compared to alternatives.
2. The proper preliminary design of the plant to fit the site chosen, and to overcome inasmuch as possible objectionable plant features.
3. An effective public information program which includes the preparation of attractive drawings and models; prepared plan presentations at public meetings, with rationale for the choice as compared to alternatives; and visits to successfully operating facilities.

Land Area Requirement

The actual area required by a thermal processing plant depends upon its size, design, site suitability, operating mode, and auxiliary facilities to be included. For an incinerator processing 50 to 75 metric tons per hour (1300 to 2000 short tons/day) the minimum site required (excluding expansion area, parking, truck storage, vehicle services areas, landfill, extensive water treating facilities, or extensive screening areas) would be about 12,000 to 16,000 square meters (3 to 4 acres). A more suitable site including some of the auxiliary requirements, but still excluding expansion and landfill areas, would be two to three times the minimum.

Plants much smaller than 50 to 75 metric tons per hour obviously require much less area, but the requirements are far from linear. It is difficult to visualize a suitable site of less than 8000 square meters (2 acres), even for a very small incinerator.

The area required for landfill of residue, siftings, flyash, and bulky materials should be calculated using information such as that presented in Table 1 of Chapter I and in Chapter II. Where possible, a landfill life of at least twenty-five years, including growth projections, should be available. This would provide the same order of magnitude as life expectancy for a thermal processing facility.

A definitive calculation of land area requirements, and major participation in site selection should be assigned to the consulting engineers.

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CHAPTER V

PLANT LAYOUT AND BUILDING DESIGN

Plant layout and building design must enhance the thermal processing facility aesthetically and functionally. Successful design will achieve the following:

1. Harmonization with the surroundings.
2. Utilization of the topographical features of the site to the greatest advantage.
3. Efficient and economical traffic flow.
4. Efficient and economical process operation.
5. Ease of housekeeping and maintenance.
6. Avoidance of nuisances and hazards associated with traffic, handling of wastes and byproducts, noise, odors, and gaseous, liquid, and solid effluents.

Aesthetic excellence in layout and design of a thermal processing plant is not necessarily at odds with achievement of reasonable costs. Where conflicts exist, evaluation of alternatives and realistic compromises will usually result in an acceptable solution. If this job is done well, the rewards will include better public acceptance as well as ease and economy of operation.

Plant Layout

Layout of buildings, roads, stacks, gas cleaning equipment, water treatment facilities, and landfill areas (if onsite residue disposal is to be practiced) is done with a view to both social and economic factors. The social factors associated with plant layout have often been neglected. However, with increasing public awareness of air and water pollution, and noise and congestion related to truck traffic, site planning must take these factors into account. For example, receiving and refuse storage are often located at the rear of the building and out of public view. In warm climates with prevailing wind patterns, the receiving area may be placed on the leeward side of the main buildings to minimize wind-carried litter and odors, and to provide workers with protection from the elements.

Hillside terrain may be used to create the impression of a low building profile to overcome the stark visual impression of a multi-story structure. The architectural design of the building structures should harmonize with surrounding buildings and terrain in such a way as to maintain the visual integrity of the neighborhood. Even tall stacks may be partially hidden from view by buildings. The materials selected for the exterior shell of the stack should be as unobstrusive as possible. Short stacks may be used in some instances at the expense of greater power requirements for induced draft (ID) fans, but such stacks must be consistent with proper dispersion of gaseous emissions.

Air cleaning equipment, such as electrostatic precipitators, cyclones, or scrubbers, will usually be installed in such a way as to be shielded from view, or they may be enclosed within the building to avoid excessive heat loss and condensation of moisture. Settling ponds and lagoons used for treatment of wastewater will normally be located at as low an elevation as possible to facilitate incoming drainage and are, therefore, seldom detrimental to the appearance of the plant when viewed from a distance. Through careful design, such small bodies of water often lend almost a park-like atmosphere which, even at close range, can enhance the appearance of the property. Retaining walls or dikes bordering the ponds should be built to withstand erosion, and must be properly maintained if these facilities are to remain an asset in terms of appearance.

Layout and design of outlying structures, including weighing stations, and maintenance buildings, garages, pumping stations, and cooling towers, should be considered as carefully as the central buildings. Their location, space profile and decor should be in harmony with the overall plan for the site. Shrubs and tree plantings are often helpful devices for shielding unsightly features of the facility. However, plantings will not take the place of peripheral fencing which is needed to keep out intruders and to retain windblown paper and trash.

Even at the design stage, consideration should be given to plant obsolescence and decommissioning of the plant. Since the anticipated life of a plant is only about 20 to 30 years, thought should be given to the eventual uses of the site so that it will continue to meet community needs. Possibilities for future development include revamping for continued use in solid waste processing, recreation, an industrial park, or even housing. Retention of as many existing natural features of the landscape as possible will facilitate conversion to other uses. When certain areas are used for landfill, great care should be exercised in moving the overburden of earth so that the land is not left in unsuitable condition for future use.

Building Design

Various views of municipal incinerators are shown in Photographs 1 to 4. Figures 6 to 8 help illustrate the relationship between buildings and equipment which is housed. That these plants can be architecturally appealing and varied in design treatment is apparent from the photographs.

From a functional point of view, a good building design promotes economy of operation and ease of maintenance. Equipment arrangement should promote uninterrupted flow of materials through the plant. Special attention must be paid to the movement of air which is sucked into the plant and through the furnaces by induced and forced draft fans to avoid drafts which carry litter and odors to working areas, and to avoid excessive space heating requirements.

VARIOUS U.S. INCINERATORS

Photograph 1

Lower Moreland Township, Pa. 250 T/D. 2 Furnaces.

Ansonia, Connecticut. 200 T/D. 2 Furnaces. Contains rotary, wet sludge burning.

Incinerator No. 5, Washington, D.C. 1500 T/D. 6 Furnaces.

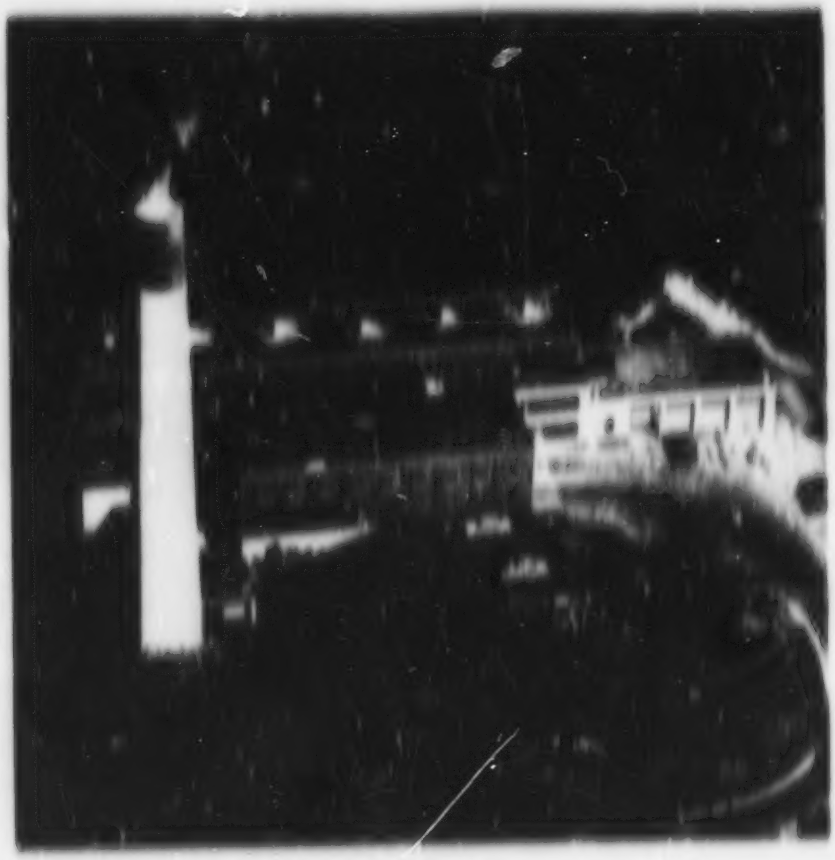
Babylon, L.I. New York. 400 T/D. 2 Furnaces.

Stamford, Connecticut. 360 T/D. 1 Furnace.

Oceanside Plant, Town of Hempstead, N.Y. 750 T/D. 3 Furnaces. Combines steam/ electric power generation and shredding raw refuse.

RAMAPO, N.Y. INCINERATOR

Photograph 2



EAST HAMILTON, ONTARIO
SUSPENSION-FIRED
STEAM PRODUCING INCINERATOR
PHOTOGRAPH 3

PHOTOGRAPH 4

MONTGOMERY COUNTY – SOUTH

This facility, with a design capacity of 600 tons per day provides 1/2 of a County wide system of municipal waste disposal. The North Plant, pictured below, forms the other half.

MONTGOMERY COUNTY – NORTH

The city of Dayton, Ohio, and other communities in the County, have used this plant and the South Plant since 1969 to dispose of solid waste. Each Rotary Kiln Unit is rated at 300 Tons/Day.

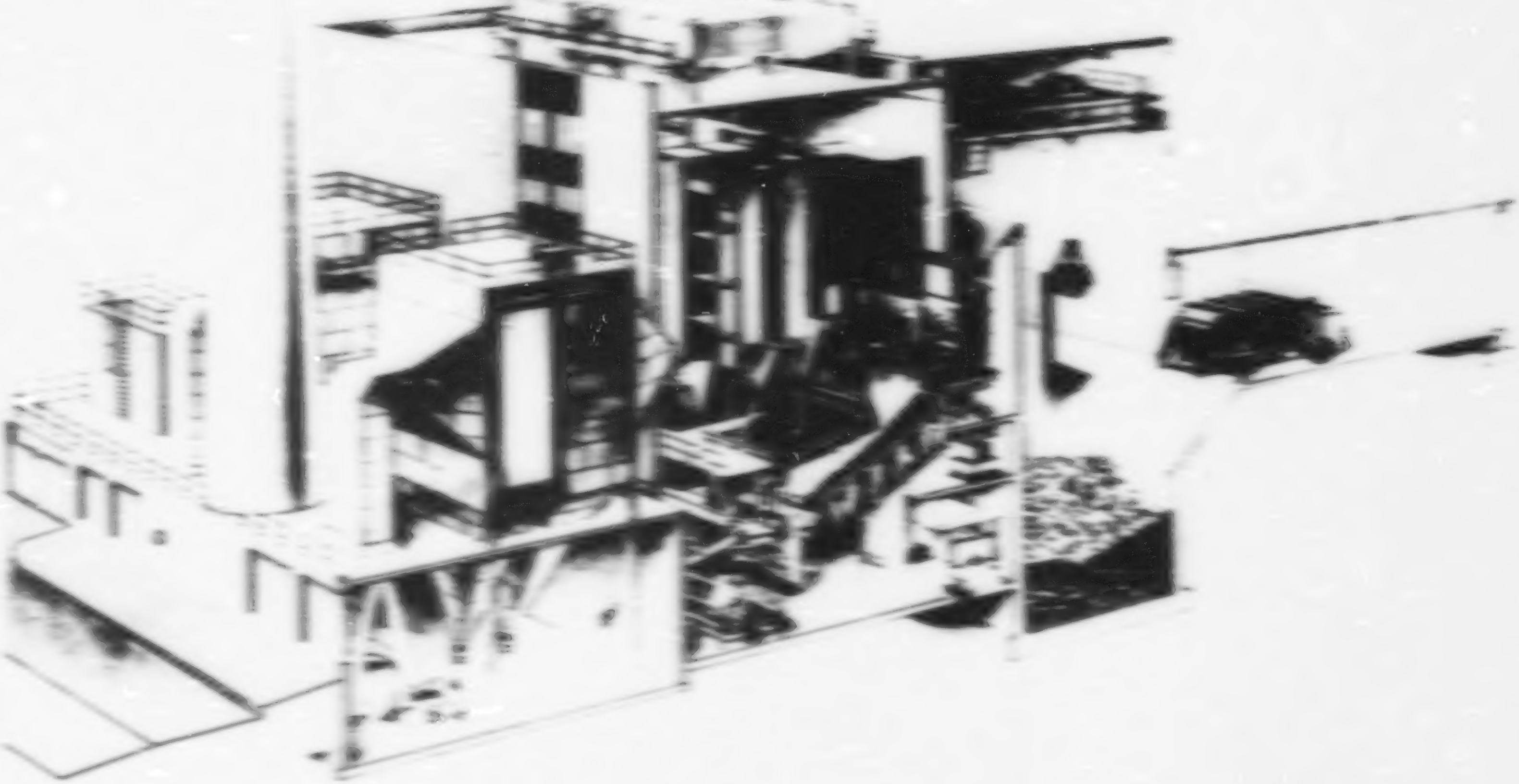


FIGURE 6. HARRISBURG, PA. STEAM PRODUCING INCINERATOR

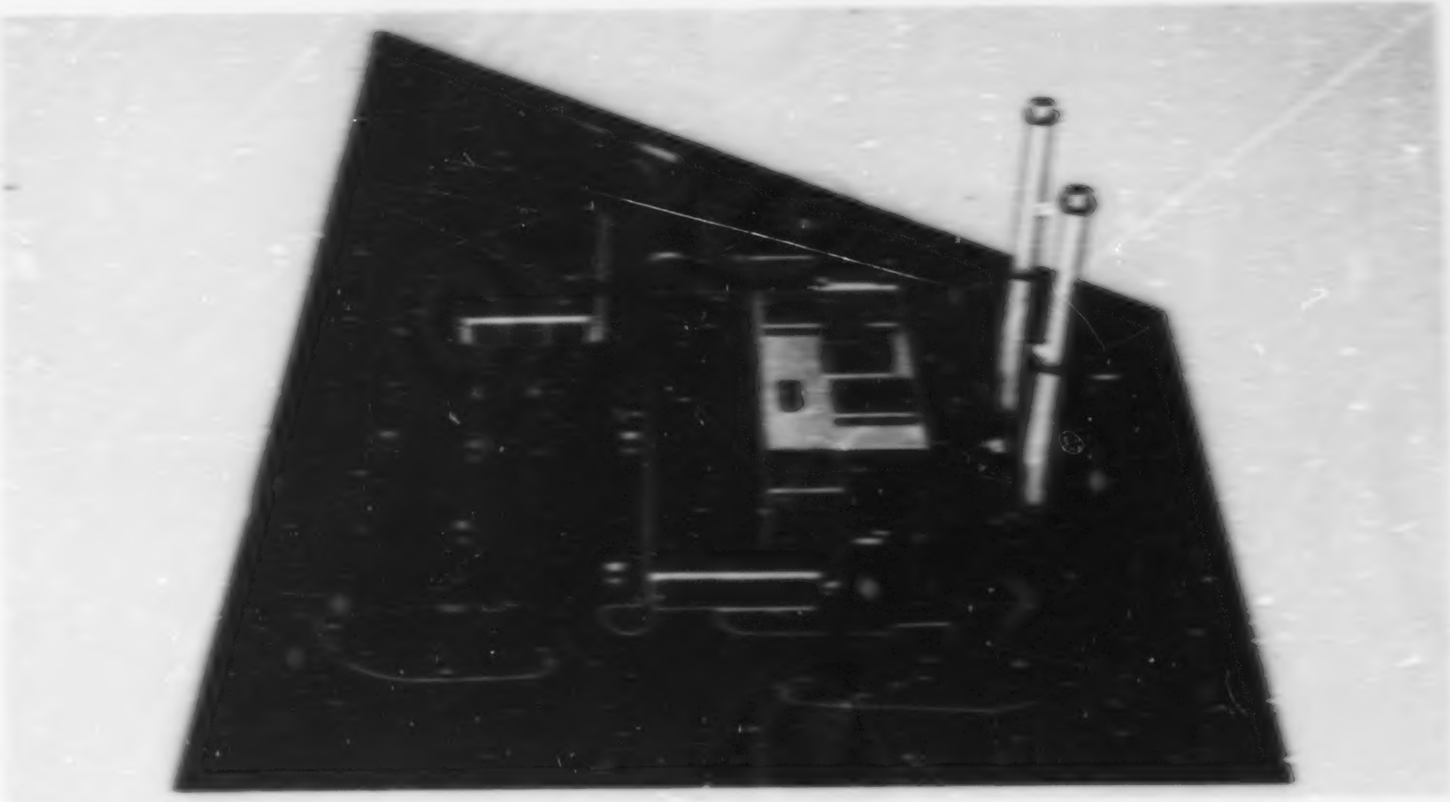


FIGURE 2. CHICAGO NORTHWEST STEAM PRODUCING INCINERATOR

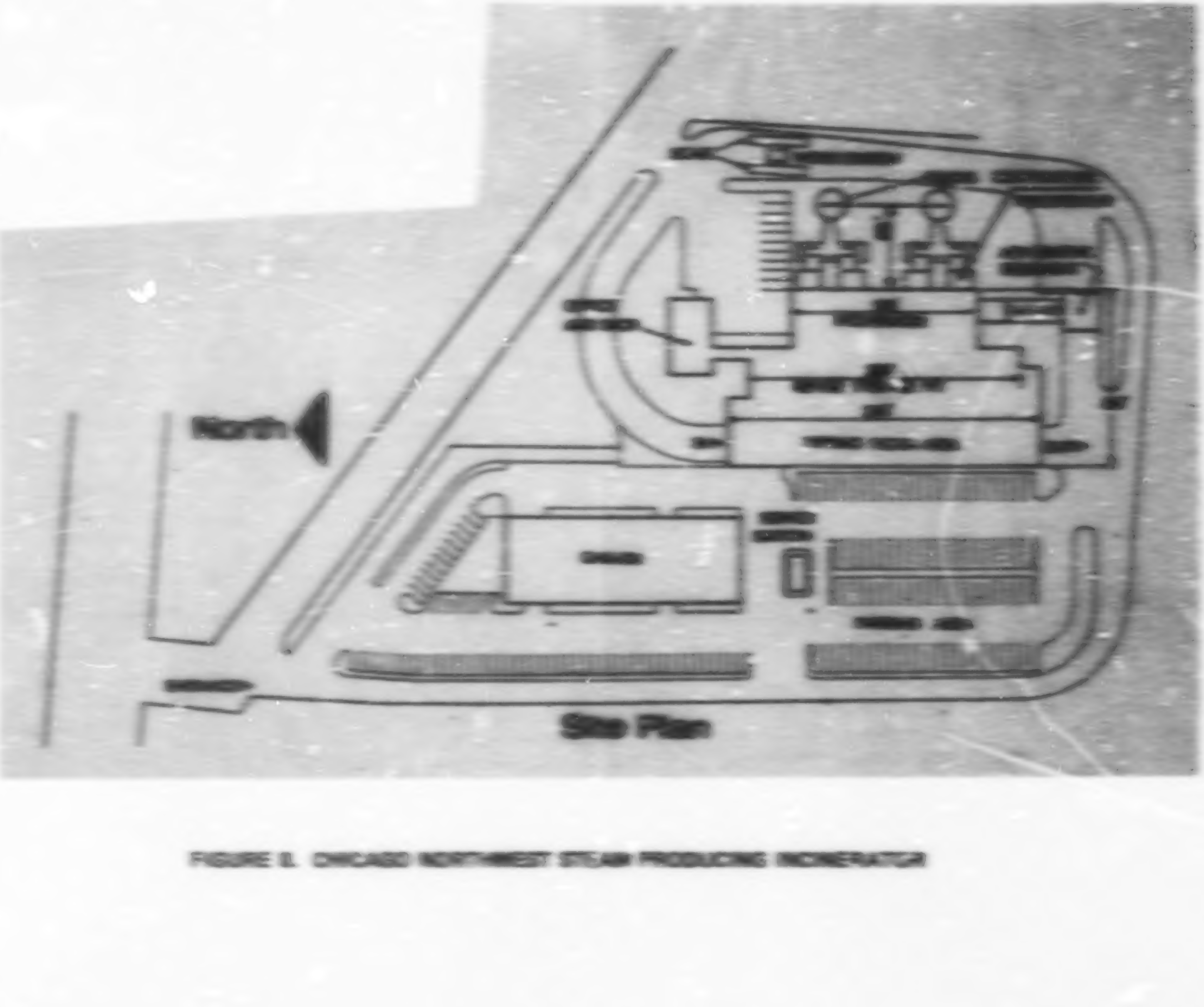

North
Site Plan

FIGURE 8. CHICAGO NORTHWEST STEAM PRODUCING INCINERATOR

One helpful design feature is to cause air to be drawn over storage pits toward the fan intakes, thus drawing pit odors into the furnaces.

Adequate working space is needed for the operators and maintenance personnel to perform their jobs efficiently. Location of work areas should be such that the many operating tasks can be performed conveniently without wasted time and effort. A large proportion of the maintenance required will be performed on the operating floor, since most of the equipment is too large to be moved to another area. Adequate space must be provided for making repairs, with special attention to headroom, clearances for replacement of large equipment items, and for movement of mobile equipment.

Operators are unanimous in asking that all facilities, materials, equipment, tools and parts required for normal plant operation and maintenance be included in the contract for the original design, rather than being added piecemeal after the plant is in operation. A liberal number of electrical outlets for power tools and welding equipment should be provided at strategic locations throughout the building. Where compressed air and steam lines are used, an adequate number of valved connections should be provided to eliminate the need for long runs of hose. The same applies to service water used for floor washing and other plant use.

The building should be constructed of durable, high quality materials and fixtures to minimize the problems of cleaning, painting, and resurfacing. Some of the materials which meet these requirements, include concrete, ceramic tile, and metals which are not subject to corrosion. Surface finishes must be dense and durable. Coving installed along the edges of floors will reduce the accumulation of debris and allow easier cleaning. Exposed piping and ductwork tend to collect dirt and should be enclosed but accessible wherever possible. Because solid waste processing plants are subjected to unusually heavy wear and considerable dirt, nothing less than the most rugged materials are acceptable, if operating and maintenance problems are to be avoided.

Structural components of the building should have sufficient bracing to prevent sway from crane operation. Allowance must be made for thermal expansion and contraction of structures in close proximity to furnaces and other hot areas.

Stairways should provide convenient access to each floor, and clearances, including entrance doors, should be wide enough to accommodate supplies and equipment to be carried up the stairs. An elevator for personnel and for moving heavy equipment may be desirable, especially in larger plants.

An adequate number of well designed floor drains in strategic locations are a necessity. Some plants use open sluice drains covered by subway grating in preference to buried pipes to permit easy removal of obstructions. Plans should show drain and floor elevations: the note "slope to drain" is seldom sufficient.

The safety and well-being of personnel is a prime consideration. For example, work areas should be made as pleasant as possible through the use of attractive colors. Adequate ventilation and lighting must be provided. When these factors are properly considered, the advantages of high morale and good performance by the plant workers are more likely to prevail. A checklist based on the suggestions of incinerator plant operators is available for review by designers.[1]

Personnel Facilities. Comfortable surroundings are important in attracting and holding competent personnel. Considerable attention should be given to the proper location and design of showers, lockers, toilets, wash rooms, vending machine areas, and lunch rooms. They must be comfortable and attractive, as well as adequately sized and well equipped. Sanitary facilities must be provided for women who may visit or be employed at the plant. All the foregoing facilities are best located adjacent to operating areas, but in a wing or section of the building separated from the dirt, dust and noise of plant operations. Drinking water should be available on every floor and within 200 feet of employee stations.

Special attention directed toward the use of interesting color schemes will alleviate monotony. Materials used should require little maintenance and be easily cleaned. It is good practice for the original contract to provide for all necessary fixtures including furniture, window blinds, floor cabinets, etc.

The receiving area should be isolated from the processing section of the plant to discourage unauthorized persons from walking through the furnace rooms and other operating areas. Therefore, it may be necessary to provide well marked toilets and wash rooms for use by collection crews. Snack bars and a pay telephone to the receiving area are also desirable.

Administrative Offices. Administrative areas, including offices, conference rooms, and supply storage should be carefully planned, adequately sized, and properly furnished. In larger plants, the superintendent, foremen and clerical workers may need an office which is free from the distractions of the operators' desks and the control room, though some critical process information may be automatically transmitted into this area.

Offices should be attractive and air conditioned to improve efficiency. An adequate number of file cabinets and storage space for office supplies will be required. A conference room for staff briefings, safety discussions and training purposes may be a worthwhile investment. Smaller plants may effectively combine all administrative activities in the same area.

Weighmaster's Office. The motor truck scale is an indispensable feature of all modern solid waste processing plants. Although the weighing activities may be conducted alongside the access road outside the incinerator plant, many operators prefer that the control room and platform be located inside the building at the entrance to the turning and tipping area. Provided the scale is of electronic or semi-electronic load cell type, there is considerable flexibility in locating the scale room with respect to the platform.

The weighmaster's office should be fitted with ample glassed area to observe the movement of weigh scale traffic. He should have adequate means of communicating with the driver, including possible inclusion of stop and go signal lights and/or an intercom system.

This office should be well lighted and ventilated with consideration given to air conditioning. The equipment supplied has to be adequate to handle all transactions and storage records, for example, credit card or even cash transactions may be contemplated.

Maintenance and Repair Facilities. It is advisable that all facilities, materials, equipment, tools, and parts needed to maintain the plant be supplied as part of the original contract. Well equipped machine shops and storage areas are essential, since a major portion of the repairs and major maintenance work will normally be done on site using plant personnel. Ample storage space is needed for electrical, mechanical, and refractory parts. At least one spare is provided for most key equipment items including grate parts, motors, speed reducers and drives. Floor and shelf space should be provided for large items, and drawers and bins for smaller ones. Large municipalities may have central maintenance and repair facilities, or contract maintenance may be envisioned, eliminating some of the above requirements.

Laboratory. The principal purpose of the laboratory is to insure that environmental regulations are being met. A secondary purpose of the laboratory is to perform tests which will be indicative of facility performance, including percent burnout of the residue from incineration and composition of incoming waste. The laboratory should not be too elaborate, but should provide sufficient space to perform the required tests. File cabinets for test records and sample storage shelves are normal laboratory appurtenances. Some thermal processing plants which produce fuels and other saleable materials may have specialized quality control testing requirements. For large or complex facilities, where full-time laboratory personnel are contemplated, an office area must be provided.

Processing Areas. Design of the various processing areas will be extensively treated in subsequent Chapters. Since the building is basically an enclosure of the processing areas, process equipment is at least tentatively sized and located prior to design of the building. However, interchange must exist between process and building designers to insure complete compatibility.

Interior Lighting. Lighting within the plant should be adequate to insure that tasks can be performed easily and with safety. Recommended lighting standards are published by the Illuminating Engineering Society.[7] Lighting standards for performing certain tasks similar to those performed at incinerators are shown in Table 21.

Consideration should be given to shielding of open lights to lessen the hazard of breakage. Explosion-proof lighting will be necessary in sections of pyrolysis plants which produce fuels.

Table 21

LIGHTING STANDARDS APPLICABLE AT INCINERATORS[a]

Office and industrial tasks	Foot-candles on task
Loading and trucking	20
Corridors, elevators, stairways	20
Rough, easy assembly work	30
Reading high-contrast or well-printed material, tasks and areas not involving critical or prolonged seeing such as conferences, interviews, inactive files, and washrooms	30
Medium bench and machine work, rough grinding, medium buffing and polishing, difficult inspection	100
Regular office work, reading good reproductions, reading or transcribing hand writing in hard pencil or poor paper, active filing, indexing references, mail sorting	100

Design for Fire, Explosion, and Other Hazards

Safety. A number of safety-related design suggestions have been included in the foregoing sections dealing with specific items of plant equipment. Safety of operators and repair crews is promoted not only by supplying safety equipment, such as hard hats and special shoes, but by thoughtful design, layout, and specification of equipment. For example, sufficient space must be provided for walkways, and for required maintenance. As discussed in Chapter II, federal occupational safety and health regulations, and insurance standards provide excellent safety guidelines.

It is essential to eliminate the hazard of objects falling onto personnel working in areas below. Equipment which requires frequent maintenance should not be located directly above an operating platform. Floor openings or hatches should be provided with curbs to prevent objects from rolling or being pushed over the edge. Guard rails, appropriately placed, are effective in prevention of falls.

Improper specification or use of ladders frequently results in injuries. Therefore, permanent ladders should be specified where necessary, but ladders and steep stairs are to be avoided where materials must be carried. Hoop cages are required on tall vertical ladders.

Electrical switch gear should be mounted in moisture and dust tight enclosures and not be installed in locations which may be subject to wet conditions, standing water, dust or potentially explosive vapors. Placement of thick rubber mats on the floor in front of electrical panels is a good precautionary measure.

Doorways used for receiving and removing bulky equipment should be of sufficient height and width to accommodate the equipment and the truck or fork lift used. Sheaved hoists mounted on trolleys may be required in some areas. Doors should open either in or out, whichever is consistent with maximum safety.

Fire Protection. Hydrants or post indicator valves (PIV) must be provided at locations specified by local fire regulations. At least two PIV's should be located at the tipping floor area for use in extinguishing pit fires. Others are desirable in the area of feed chutes, and at the discharge end of the burning stoker in an incinerator. Good practice requires standardization of hose couplings and fittings used for in-plant fire control with those used by the local fire department. Fire extinguishers of the dry powder or carbon dioxide types may be installed near the entrance and exit doors, in areas of exceptional fire hazard, and in maintenance shops. American Petroleum Institute guidelines are available to design fuel storage and handling facilities.

First Aid. Well stocked first aid cabinets should be provided at several locations throughout the plant for treatment of minor injuries. These cabinets should never be locked. Safety fountains for the face and eyes, and safety showers must be considered, particularly where water treatment and other chemicals are used. Stretchers and blankets for use by injured personnel are a necessity.

Noise Considerations. A typical thermal processing plant will contain many noise sources which may emit sound levels ranging from acceptable to annoying and potentially harmful. These may be within or outside the plant, including vehicles, fans, shredders, conveyors, burners, feeders, cooling towers and so forth. Measured noise levels of some sources at various distances from the source are given in Table 22.

When designing buildings, two classes of noise must be dealt with: (1) internal plant noise which is an industrial hygiene problem; (2) noise projected beyond the plant boundaries, which becomes a public nuisance. Methods used for noise abatement include enclosure of equipment within buildings, use of sound absorbing materials inside equipment housings and sound barriers, use of low speed fans, selection of quiet hydraulic equipment, vibration mounting of rotating equipment, and other measures of this nature. If the designer is not familiar with the latest developments in noise abatement, he should obtain the services of a competent consultant who specializes in this field.

As sound waves travel through the air and over different kinds of terrain, the sound energy is gradually attenuated until it is no longer a problem. Therefore, the most troublesome noise generating equipment should be located the farthest distance from the property line which is downstream from the prevailing wind direction. A graph showing the attenuation of noise as it propagates from a point source and radiates to various distances is shown in Figure 9.

Plant Exterior

Stacks. Stacks are in reality part of the process equipment, but their location, size, height, and appearance impose a burden on the building designer. Dispersion and draft requirements determine the height and diameter. Natural draft chimneys or stacks have an advantage over stacks with an induced draft (ID) fans, in that they require neither a source of power nor fan maintenance. However, present day requirements for sophisticated air pollution control equipment with inherent pressure losses, and the usual desire to maintain negative pressure within the thermal processing equipment to avoid odor release, dictates the use of ID fans. The stack height is then chosen primarily by dispersion considerations. A single stack should serve no more than two furnaces. When one stack services two furnaces, individual dampers are required for proper control of draft.

Materials used for chimney linings must be carefully selected. The most critical service occurs during startup and shutdown operations when the combustion gases are cool and moisture tends to condense in the pores of the refractory linings. Acid gases dissolved in the condensate formed aggravates the problem of achieving acceptable service life of stack lining materials. More flexibility is available in the choice of external materials.

Roadways, Sidewalks and Parking Areas. Data on peak load truck arrivals are necessary for adequate design. Road width is set to provide passage around stalled vehicles. Entrance to the site should be carefully planned to avoid the use of heavily traveled highways. Where feasible, an entrance lane

Table 22

DISPOSAL OF REFUSE AND OTHER WASTE
MEASUREMENTS OF PEAK NOISE LEVELS IN, AND NEAR, REFUSE TREATMENT PLANTS[4]

PLANT NOISE LEVELS

A. External Measurements

	Plant	Location	Noise Level	Site
1	Refuse vehicle starting	at 7.5 metres	84 dB(A)	C
2	Refuse vehicle on level ground; steady speed	at 7.5 metres	80 dB(A)	C
3	Refuse vehicle on slope, steady speed	at 7.5 metres	83 dB(A)	C & D
4	Forced draught fan	at 3 metres	76 dB(A)	C
5	Induced draught fan	at 30 metres	71 dB(A)	C
6	Cooling tower	at 30 metres facing louvres	69 dB(A)	M
7	Cooling tower	at 130 metres facing louvres	60 dB(A)	M
8	Cooling tower	at 270 metres facing louvres	54 dB(A)	M
9	General plant noise* (mostly de-duster)	at 110 metres from wall	52-53 dB(A)	C
10	General plant noise*	at 300 metres from plant	45-46 dB(A) (Hum of de-duster clearly audible)	C
11	General plant noise* (mainly fan noise)	at 50 metres from plant	57 dB(A)	D
12	General plant noise*	at 100 metres approx.	53 dB(A)	P
13	Residuals (conveyor and chute)	at 10 metres	75 dB(A)	D
14	Several vehicles discharging	at 15 metres from entrance (outside reception hall)	62 dB(A)	C
15	Magnetic separators + clinker & fly ash conveyor	at 10 metres	82 dB(A)	P
16	Pulveriser only	at 10 metres	70 dB(A)	F
17	Vibratory feeder	at 10 metres	81-82 dB(A)	F
18	Pulveriser with vibratory feeder in operation	at 10 metres	79-83 dB(A)	F

* Variable according to plant layout and other noise sources

(continued)

Table 22

DISPOSAL OF REFUSE AND OTHER WASTE
MEASUREMENTS OF PEAK NOISE LEVELS IN, AND NEAR, REFUSE TREATMENT PLANTS[a] (concluded)

B. Internal Plant Noise†

1	Metal press	at 3 metres	84-86 dB(A) (mostly clangs)	C
2	Cardboard press	at 3 metres	86-88 dB(A)	C & D
3	Induced draught fan in reverberant conditions	at 3 metres	91 dB(A)	D
4	Collection vehicle, tipping	at 3 metres approximately	90-92 dB(A)	D
5	Water pump, reverberant conditions	at 3 metres	91 dB(A)	D

C. Internal Environmental Noise Levels

	Predominant Noise Source	Location	Noise Level	Site
1	3 vehicles discharging	Reception hall	88-91 dB(A)	C
2	One conveyor plus	In elevator room on "bridge"	87 dB(A)	C
3	Conveyor	In elevator room on "bridge"	79 dB(A)	C
4	General plant noise[a]	Inside separation and sorting room	89-91 dB(A)	C
5	General plant noise[a]	Incineration room	78-82 dB(A)	C
6	General plant noise[a]	Incineration room (by control desk)	80 dB(A)	D
7	Refuse feed chute	Inside incineration room	100 dB(A)	D
8	4 boilers in use	Inside boiler house	81 dB(A)	P
9	Turbines	Inside turbine hall	88 dB(A) (mainly whine)	P

Measuring notes:
C Castle Bromwich Refuse Disposal Works
D Direct Incineration Plant, Derby
P Usine d'Issy-les-Moulineaux, Paris
M Manufacturers' Information
F Folkestone Road Refuse Pulveriser, London, E.6

†The external noise level due to noise generated inside the plant will depend on the insulation of the walls, and any openings in them, the internal acoustics and the distance of the measuring point. It is important to note that there is always a considerably greater reduction in noise transmitted from inside a building to outside, than vice-versa.

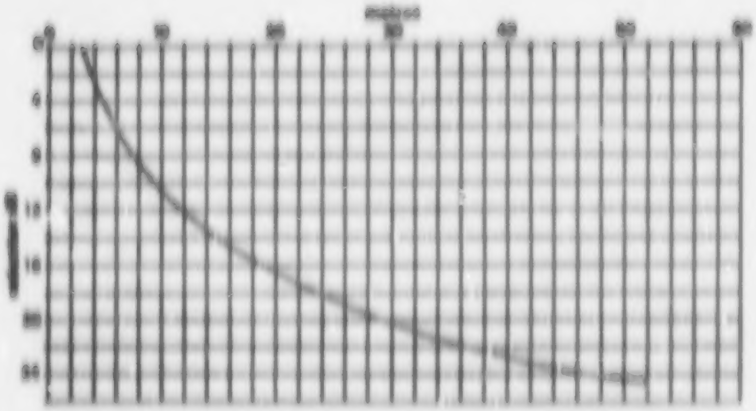


FIGURE 8. A GRAPH OF THE REDUCTION OF NOISE (dB) OVER DISTANCE (M) FOR A POINT SOURCE OF NOISE[4]

parallel to the highway will permit trucks to reduce speed with minimum roadway traffic interference.

Onsite roads will make efficient use of space not needed for other facilities. Where possible, a separate entrance and exit will allow unidirectional traffic flow. Roads should be hard surfaced and designed for heavy loads. Rough surfaces provide good tire traction. Grades should not be too steep. In general, grades for short distance truck travel will not exceed seven percent uphill and ten percent downhill. Sharp curves and blind spots should be avoided, and curbing, posts, or guardrails used to confine traffic to roadways.

Parking areas are provided for trucks which are temporarily out of service or are parked overnight. Parked trucks should not interfere with the normal flow of traffic through the plant. In severe climates, indoor truck parking may be advisable. Part of the tipping floor can be used for this purpose, but a separate area should be available where extensive parking is to be practiced. Separate parking should be provided for automobiles used by plant personnel and visitors.

Sidewalks connecting the parking lots with the plant buildings should be elevated sufficiently to permit water to run off. If sidewalks are used to move heavy equipment between the main building and the maintenance shop, care must be taken to insure that they are durable and wide enough for the load.

Fuel Tankage. Fuel tankage needed for pyrolysis products or for plant operation will be included in the design specifications. Gasoline or diesel fuel tanks and pumps may be required for maintenance and administrative vehicles, as well as for trucks used in hauling residue, flyash and siftings. Bulldozers and other earth moving equipment used on adjoining landfill sites usually require fueling at the plant. Building space heating also requires fuel tankage, unless natural gas or internally generated heat is used. Auxiliary power generators, if provided, will normally be run on diesel fuel, gasoline, or LPG.

As can be seen, fuel tankage may be practically an inconsequential site problem, as for standard refractory furnace incinerators; or such tankage may be an important consideration, as with pyrolysis plants, or steam producing incinerators with standby oil burner equipment. Fuel tanks must be properly spaced for safety reasons and can require large land areas if located above ground. U.S. Environmental Protection Agency spill prevention control guidelines must be consulted.[9]

Special Solids Handling. Some thermal processing plants employ shredders and resource recovery systems to recover ferrous metals and other materials. These will be described in chapter XVII. Where salvage materials are recovered, storage areas must be provided. Outside storage areas provide a real challenge for the designer to maintain aesthetic values, since storage of ferrous scrap and other materials can be very unsightly. Indoor storage is expensive.

Landscaping. By use of adequate plantings of trees and shrubs, unsightly activities such as unloading or residue handling can be effectively screened from view. A small, well-maintained garden patch strategically located near the main plant entrance can provide a pleasant focal point for visitors and plant personnel alike. At least one plant was surrounded with an earthworks or berm, creating the impression of low building profile.

Additional costs incurred for landscaping are often effective in achieving public acceptance and will help to maintain the land value of the site itself, and of the surrounding community.

Fencing and Lighting. Durable perimeter fencing is a prerequisite for adequate plant security in areas subject to vandalism. The usual fence is a minimum of six feet high with three strands of barbed wire projected at a 45° angle at the top. Commonly available cyclone fence is adequate, provided it is fabricated from heavy gauge wire of low-maintenance, rust-proof metal. The entrance gate should be constructed of materials which are visually compatible with the fence. The number of additional entrances to the grounds are held to a minimum to reduce the chance of unauthorized entrance.

Floodlighting of the immediate area surrounding the plant is important both for the safety of the personnel working at night and for security reasons. Floodlights may be affixed to the outside walls of the main building, unless such location creates undesirable glare when viewed from the surrounding area. If this is the case, lighting standards erected at a distance from the building can be used to direct the light toward the structure. Light stands should also be provided along the on-site roadways used by collection and other vehicles. The intensity of the outdoor lighting will vary, depending on whether or not the area is used for the performance of required tasks.

Traffic Control. Signs used for control of traffic should be carefully located, simply worded, and should make use of large lettering symbols. Where one-way control of traffic is desired, the entrances and exits should be clearly indicated. Use of directional arrows and centerline striping painted on the roadways is helpful, lessening the need for traffic signs. A stop sign or signal at the entrance to the scale platform is essential. Other signs for the direction of employee and visitors' vehicles will help in avoiding unnecessary confusion.

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CHAPTER VI

UTILITIES

Utility system requirements for thermal processing units are not greatly different than for any other large processing plant, except for the possibility of energy recovery in quantities even greater than that required for in-plant use. Incinerators can be compared to fossil fuel combustion boilers, requiring utilities for most of the following services: electrical power for motors, lighting, controls, heaters, and electrostatic precipitators; water for drinking, cooling, sprays, steam condensers, fire fighting, boiler combustion, cooling, instrumentation, and plant maintenance; sewers for the discharge of wastewaters; internal and external communications systems; and steam or fuel building and water heating, and other uses, including incinerator auxiliary fuel. Each utility must be supplied to the plant site, metered, and distributed safely and efficiently to all points of use at the site. The following discussion will first deal mainly with incinerator utility systems, and then cover utilities for pyrolysis plants.

Electric Power Systems

Electric power competes with steam as a source of energy in thermal processing systems. In older systems, almost all of the energy requirements were met by electric power. In newer systems, internally generated steam may replace electric power for fan, water pump, and other drivers.

Alternating current, three phase, 460 to 480 volt electric power is supplied to most motor drives for fans, pumps, conveyors, cranes, and other machinery. Very large motor drives commonly used for induced draft (ID) fans and shredders use higher voltages, such as 4,160 volt three phase service. Several direct current motors with SCR's (silicon-controlled rectifiers) have been installed recently to drive ID fans.

Lighting and controls are usually supplied by 120 volt, single phase circuits, stepped down by transformers from 480 volts. Alternative systems supply fluorescent lighting at 277 volts single phase. The power supply for the electrostatic precipitator is a transformer-rectifier set which steps up 240 or 480 volt alternating current to high voltage direct current, in the range of about 20,000 to 75,000 volts. The use of such high voltages demands close attention to design details and safety procedures.

The electrical power substation required to reduce transmission voltage to working voltages, the electrical power control center, the distribution system, the motor starters, and other electrical equipment represent a major capital cost. Therefore, expert engineering and cost optimization calculations should be applied to their design. The electrical system design should take into account peak power demands, and include provision for emergency standby power adequate for lighting, controls, and other devices necessary to permit orderly shutdown during power failures. Gasoline or diesel-driven generators with a suitable fuel supply can be used for emergency power.

Power requirements vary greatly from plant to plant, but the following can be used for orientation purposes:

	Installed Capacity, KW for 50 Metric Ton/Hr Incinerator
Induced draft fans (when used)	800-1600 (assumes no high energy scrubber in system)
Forced draft and other furnace fans	300-600
Conveyors and Cranes	100-300
Process Pumps	100-300
Hydraulic System Pumps	100-200
Shredders	300-1500
Lighting	less than 50
TOTAL (all services, including heating, ventilation and air conditioning)	1600-4000

As noted previously, power requirements can be reduced considerably by substitution of steam turbine drives for electric motors. Electrical facility design and installation may be governed by local authority or by the National Electrical Code (NEC).[1] NEC has been adopted as a national consensus standard by the Occupational Safety and Health Administration.[2]

Water Systems

Water may be supplied to plant booster pumps from the city water supply, from wells, or from bodies of water, such as rivers and lakes. Seawater or brackish waters may also be used for cooling. Finally a major source of water is that recycled from process or other uses. A summary of water services is provided in Table 21. Wastewater treatment is discussed in Chapter XIII.

The total amount of water required may vary from about 2 to 12 tons per ton of waste incinerated (500-3,000 gallons/short ton), depending upon design and operation.[3,4] Increasingly stringent wastewater discharge regulations now provide incentive for maximum recycle and minimum makeup of fresh water.

Where water lines may be exposed to freezing temperatures, either during normal operation or during shutdowns, pipe tracing and/or insulation may be necessary.

Steam Systems

Incinerator steam systems range from incinerators which have none at all to those which produce large quantities of steam for export. In between,

Table 23

INCINERATOR WATER SYSTEMS

Service	Water Quality	Disposition
Boiler feed water (for hot water or steam production)	Requires fresh water with extensive in-plant pretreatment	When used in-plant, condensate can be recycled with minor blowdown to other water systems.
Drinking, sanitary, and safety shower and eyewash (laboratory) water	Requires fresh water with little or no pretreatment	Discharge to sanitary sewer
Residue quenching and sluice water	Quality not critical--can use water discharged from other services	Wastewater requires treatment and sometimes cooling
Cooling water (where required for chutes, compressor after coolers, or for steam condensers)	Requires fresh or other clean water; sometimes treated to aid in corrosion prevention	May require cooling or treatment to prevent pollution by additives
Spray or scrubber water (where required for gas cooling or emission control)	Usually requires reasonably clean water free from suspended solids to prevent nozzle plugging and contamination of exit gases	Part of water evaporates; extensive recycle practiced, but requires neutralization of dissolved acid; part of water may be discharged to residue water system
Fire fighting water for hydrants, hoses, and sprinklers (with separate fire pump)	Fresh water normally stored in elevated tanks for fire fighting	When used, discharge is normally to plant wastewater sewers
Plant and vehicle wash water	Normally fresh water	Discharge to plant wastewater sewers
Surface runoff water	--	Surface waters from areas which may be contaminated with refuse should be treated as other wastewaters; uncontaminated runoff water should be handled by storm sewers

some installations have an auxiliary boiler for in-plant use, and others produce a relatively small amount of steam with convective flue gas boilers for export or in-plant use. There are plants in Europe and Japan which produce electric power from the steam[5,6], but electric power has rarely been provided in the U. S.

The production of steam for export is fully discussed in Chapter X; this discussion is limited to a brief description of in-plant uses. The most important potential in-plant uses for steam are for fan and pump drives, which were shown in a previous paragraph to be large consumers of electric power. For example, the replacement of 1,500 KW (2,011 hp) induced draft fan electric motor drives in a 50 metric ton per hour plant with steam turbines could save 60 cents per metric ton in operating costs, assuming 2 cents per KWH for electric power. Obviously, the cost of steam production must be considered, but as explained in Chapter IX, steam generation costs are at least partially offset by the advantages gained in simultaneously reducing excess air or reducing the cost of alternative methods for cooling exit flue gas.

The limitation to the use of steam for drivers is increased complexity in startup when no steam is available. This can be solved by providing electric motor drives to be used only during startup, by providing for at least one furnace to be on line at all times, by providing for auxiliary steam facilities, or by providing for "bootstrap" startup. All of these alternatives tend to be complex and somewhat costly, but the use of internally generated steam can be justified when electric power cost is high. The use of steam for building heat, air conditioning, sootblowers, and electrical power generation should also be considered.

Air and Vacuum Systems

The primary air requirement for an incinerator is, of course, for combustion. The use of forced draft and induced draft fans for this purpose is discussed in Chapter IX. Also discussed in that Chapter and in Chapter XIV is the use of air for flue gas cooling. In this section, the provision of compressed air for instrumentation, maintenance, and other plant uses will be discussed, as will the use of vacuum systems.

Many instrumentation systems are based on the use of air, although electronic instruments are a possible alternative. An instrument air system consists of a compressor and facilities to clean and dry the air. The drier usually contains a solid dessicant such as silica gel, and a means for automatic regeneration of the spent dessicant. Normally a complete spare system will be specified to insure reliability, although it is possible to store cylinder nitrogen, or to draw on the plant air compressor for emergencies, if provision is made for filtering and drying. The quantity of instrument air required will depend on an analysis of the instrumentation specified, but about 2 to 4 normal cubic meters per minute (71-141 SCFM) for a large reasonably complex plant might be expected. The compressor is usually designed for about 6.5 atmospheres absolute pressure (80 psig).

The quantity of plant air normally provided is the same order of magnitude as the instrument air supply, unless the incinerator design calls for pneumatically operated water spray nozzles. The compression pressure may be similar to or higher than the instrument air pressure. Driers are not provided, but some water is removed in after-coolers. This air is used for cleaning, pneumatically operated valves, maintenance tools, other machinery, and for sootblowers in plants where steam is generated.

Industrial vacuum cleaning systems can be a valuable addition to an incinerator plant. This must include an exhauster, dust collectors, a means for disposing of collected solids, ductwork, valves, and cleaning accessories.

Fuel Systems

Fuel requirements are very much dependent upon the design of the incinerator. In each case, the services outlined in Table 24 should be considered. Every effort should be made to minimize fuel requirements by using energy available from refuse combustion.

Pumps are of course required to deliver liquid fuels to the necessary services. Tanks are usually underground, but larger tanks may be above ground.

Communication Systems

External telephone communications are provided either by a trunk line from the main switchboard serving the municipality, with or without direct dialing to various plant phones; or by a separate phone system with several lines. Communications within the plant can be provided by an intercom system with paging. Either general or selective paging through loudspeakers can be arranged from multiple desk telephone and wall mounted intercom stations. Intercom stations in noisy areas must be equipped with acoustic booths, and visible signals can be used where necessary.

The use of color closed-circuit television monitoring for observing combustion, critical operations, and stack emissions is becoming common and should be considered for all new installations.

Utilities for Pyrolysis Processes

Since little commercial experience is yet available on pyrolysis of municipal solid waste, there is relatively little hard data on utility requirements. The following discussion will serve as an introduction to some of the expected requirements for several processes discussed in Chapter XI, Pyrolysis.

Monsanto Envirochem LANDGARD Process. Power and water requirements for the LANDGARD System, designed to produce steam, may be expected to be similar to that required for incinerators, since complete combustion of offgases with scrubbing and removal of solid residues are practiced. These may approach 70 to 75 KWH per metric ton of solid waste for power and about 2 to 4 tons per ton for water. Fuel requirements are much higher than for incineration,

Table 24

INCINERATOR FUEL REQUIREMENTS

Service	Fuels Considered	Comments
Building heat, water heaters, auxiliary boilers	No. 2 or No. 4 fuel oil; natural gas	Depends on climate; normally only offices, labs, shops, etc. heated
Incinerator light off	Often torch used with no fuel; kerosene, No. 2 fuel oil	Relatively small quantity required, if any
Vehicles	Gasoline; diesel fuel	Incinerator site sometimes serves as storage area for refuse trucks
Standby and supplemental fuel for steam generation	No. 2, No. 4, No. 5, or No. 6 low sulfur fuel oil; waste fuels (e.g., crankcase oil); natural gas	Depends on location and availability of fuels; waste fuels may require special precautions to avoid fouling and air pollution
Flue Gas Reheat	No. 2 fuel oil; natural gas (or bypass hot flue gas)	Sometimes required to minimize plumes caused by use of scrubbers for air pollution control

about 0.03 tons of fuel oil per ton (one million BTU per short ton). However, the high cost of utilities in the LANDGARD System is more than offset by the sale of steam, which could also be used internally to decrease electric power consumption. A LANDGARD plant in Baltimore should be in operation in 1976.

Occidental Process. The first Occidental plant, designed to produce gaseous and liquid fuels, will not be in operation until late 1976. It is expected to use about 0.0025 tons of fuel oil per ton of solid waste (106,000 BTU/ST), and about 50 KWH/MT of electrical power. Water use will be about 0.35 tons per ton.

Union Carbide PUROX Process. The PUROX Process, which has been operated in a 200 ton per day pilot plant, is designed to produce a fuel gas by partial oxidation with oxygen. The electrical power requirement projected is about 130 to 140 KWH per metric ton. Most of this power is used for air separation to produce oxygen. The oxygen may be produced on-site or purchased where available, reducing the actual pyrolysis plant power consumption to a low value. As pointed out in Chapter XI, the fuel gas produced in the PUROX Process can be used to produce power greatly in excess of that required for oxygen generation and other plant uses.

Fuel and steam requirements in the PUROX Process are equivalent to about 0.02 to 0.03 tons of fuel oil per ton (0.8 million BTU/ST), much higher than normally required for incineration. Again, this requirement is greatly exceeded by the amount of fuel generated. Water requirement is believed to be similar to that required for incineration.

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CHAPTER VII

WEIGHING

Weighing of vehicles carrying incoming solid waste and outgoing residue, fly ash, other waste materials, and salvage materials, if any, is an integral part of thermal process operations. Correct weights are needed to assist to cost control, manpower scheduling, budgeting, planning, as the basis for billing the users of the facility, and for residue hauling charges.

Weigh scale data collected on cards, tape or in other forms are necessary for determination of the effective capacity and efficiency of the plant. The weight of incoming waste and outgoing residues, combined with analyses for these materials, permits calculation of overall efficiency. If weighing information is in haphazard form or is inaccurate, results will be unacceptable as a measure of plant performance. Aside from the purposes of the guarantees on a new plant, periodic efficiency determinations are helpful in detecting and analyzing factors which affect plant performance, e.g. to calculate and determine the relationship of excess air on carbon burnout for incinerators. Efficiency data may also be useful in scheduling inspections and repairs.

The determination of optimum pickup routes and arrival times is aided by knowledge of dates and times of arrival printed on the weigh tickets. This is particularly important if a facility is running at or near capacity, or if the dump pit is of inadequate size. This information also assists in making effective use of the manpower available, and checking the efficiency of pick-up crews.

A further benefit derived from the availability of complete and accurate weigh scale data is the ability to do effective planning. For example, analysis of weigh data exposes trends in the quantity of waste material received, and aids in the prediction of life for existing landfill sites used for disposal of residue. Decisions relating to expansion of existing facilities or replacement with new facilities depend heavily on the evaluation of weigh scale records.

Finally, the service provided to the various communities using the facility can be most easily measured in units of weight received. Where fees are charged to commercial and industrial waste haulers or to other communities, they are usually assessed by weighing the incoming vehicle loads.

Scale Description

Motor truck scales normally consist of a platform suspended on a structure which transmits the weight of an impressed load to a weigh head, where the weight is indicated and recorded. The entire weighing mechanism, with the exception of the weigh head, is installed within a sub-surface weigh pit which is usually constructed of poured concrete. The scale pit is designed for adequate drainage, usually with a sump and a pump. An enclosed weigh house is provided for the weighmaster either as part of the incinerator building, or as a separate structure, depending upon traffic flow and positioning of the scale.

Scale Types

There are three basic types of scales in general use today: (1) fully mechanical (2) combination system of mechanical levers with a single electronic load cell and (3) fully electronic load cell types. Mechanical scales are perhaps the most common type, but electronic scales are now in favor.

The weighing mechanism of a fully mechanical scale consists of a system of levers, pivots (knife edges) and fulcrums (bearing blocks). The mechanical components are installed in a reinforced concrete pit sized to accommodate the platform. The pit is normally 4 to 6 feet in depth. A structural steel assembly called the weighbridge is used to support the platform and to transmit its weight onto the lever system beneath. The applied load is reduced by a factor of approximately 400 to 1 by the lever mechanism before it is transmitted to the weigh head. The weigh head usually consists of a dial indicator and a printer which records on a card the date and time of the transaction, and the weight of the vehicle. Identifying information, including the hauler's name and address, the truck number, etc., may be transferred to the ticket from an embossed credit card or may be written in by hand. Tare weight and net weight are transcribed manually. One section of the ticket may be given to the driver as a receipt, with additional copies being retained as a permanent record. The use of a manually adjusted beam balance scale registering device in place of a direct reading dial indicator and printer is not recommended because it is subject to operator manipulation.

A combination mechanical-electronic scale utilizes a single electronic load cell (strain gauge transducer) which in turn transmits a milliampere signal to the weigh head. Because this signal is carried by a cable, the weigh head can be located at any distance up to 2000 feet from the scale platform. Most often, however, the signal is relayed to a weigh house which is in close proximity to the scale platform, where the weighmaster conducts the transaction in a weather protected environment. The signal from the load cell may also be used to operate additional indicating, printing, and totalizing accessories which are not available with a fully mechanical scale.

The fully electronic load cell scales are available from all the major scale manufacturers. These scales use no lever mechanisms, but utilize 4, 6 or 8 load cell measuring devices located at equally spaced weight support points located beneath the weighbridge. Proponents of the fully electronic scale claim that their higher cost is offset by lower maintenance costs due to elimination of the lever system, and by cost savings associated with simpler design of the weigh pit. Since electronic readout capability is a characteristic of either the full load cell or the combination mechanical-electronic scales, the advantages of one type over the other appear to be overstated in some instances. A full load cell installation should never be used where the scale pit is on low ground and is subject to flooding, since high replacement costs for load cells have been experienced after prolonged periods of submersion.

Size and Capacity

Platform lengths may vary from 6.7 to 21.3 meters (22 to 70 feet) with capacities of 20 to 75 tons, but typical scale platforms are 3x10.4 meters (10x34 feet) (30 ton capacity) or 3x18.3 meters (10x60 feet) (60 ton capacity). The platform length specified should be based on the distance between the front and rear axles, with sufficient allowance for imprecise positioning of the load. For example, a trailer with a between-axle length of 40 feet can be weighed on a 50 foot platform scale, but positioning of the truck on the platform must be nearly perfect or weighing errors will result. An 18.3 meter (60 foot) platform is more practical when large trailers must be weighed, as might be the case when solid waste transfer stations are used. At the time a scale is specified, consideration should be given to the types of equipment which may have to be weighed at some future date.

Although highly automated weighing systems can handle well over 60 trucks per hour (600 metric tons/hr. at 10 metric tons per truck), incinerators with a capacity greater than 1,000 metric tons per day may use two or more scales to avoid traffic delays and to insure reliability.

Accuracy

The accuracy for new motor truck scales produced by the major manufacturers is within the National Bureau of Standards recommendation of 0.1 percent of the applied load,[1] although the accuracy required is only about ±1 percent. However, the scale should meet the requirements of state and local statutes related to weights and measures. For example, for 0.1 percent accuracy, a full load on a 50 ton scale must be accurate to within 100 pounds of the actual weight applied. Repeatability within 0.01 percent and linearity within 0.05 percent are claimed by at least one scale manufacturer.

Both mechanical and electronic scales should be tested under load about three to four times per year. The testing should include: (1) checking for a change in indicated weight as a heavy load is moved from the front to the back of the scale (2) observing the action of the dial during weighing or for an irregularity or "catch" in dial motion (3) testing the scale with test weights and (4) inspections as discussed in the paragraphs on maintenance.

Accessories

Among the large number of optional features available with either of the electronic types of scales are:

- Electronic indicator for direct reading of weight in digital form.
- Digital tare device for automatically subtracting the tare weight of the truck.
- Automatic zero tracking system for correction of load cell temperature deviation, or error due to debris or ice accumulation on the scale platform.

- Vibration suppression feature.
- Pound-Kilogram selector switch (or specify provision for easy modification at a later time).
- Automatic time and date stamp.
- Data accumulator for totallizing of all weights taken in a given period of time.
- Combination ticket and roll tape printer (roll tape provides a permanent record in the event that tickets are lost).
- Motion detector which will not permit weight printing until the load is at rest (prevents printing at high or low swing points).
- Plate holder (credit card type) for printing truck identification numbers along with the weight print. Alternatively, a keyboard for manually punching the identifying numbers prior to weight printing may be specified.
- Automatic-Manual switch (manual mode for use when identification plate is not available).

Prices

The 1974 price for a 10.4 meter (34 foot) mechanical motor truck scale including platform steel and basic weigh head was $8,000. A mechanical scale with single load cell and remote electronic printing was priced at about $10,000, and a full electronic load cell scale at about $10,000. Approximately $2,600 is added to the above prices when scale lengths of 15.2 or 18.3 meters (50 or 60 feet) are specified. Prices include installation but do not include construction of the concrete weigh pit.

The weigh pit is normally designed by the engineering contractor, using dimensions supplied by the scale manufacturer. Actual construction of the pit may be subcontracted using local labor. The construction cost for a weigh pit for a 3x10.4 meter (10x34 foot) scale may range from $8,000 to $11,000, while a 3x18.3 meter (10x60 foot) pit may range from $10,000 to more than $20,000. The factors affecting the cost of pit construction include load bearing properties of the soil, and especially restrictive work rules which may be in effect at the construction site.

Load cells are very rugged and seldom fail unless subjected to misuse. The cost of replacement is about $600 per cell, plus installation costs.

Operation

The weighing operation begins by positioning the truck on the platform. The weighmaster then takes the proper card from the file (automatic sequence) and actuates thn printing mechanism. A weigh ticket showing the correct date and time is issued. This ticket serves as a receipt for the driver, and as a permanent plant record. A typical weigh ticket is shown in Figure 10. The transaction is simultaneously punched on a tape or data card, depending on the type of equipment provided. Such identifying information as truck number, route number, municipality, or billing code is also shown.

During the above procedure, the tare weight of the vehicle, obtained during a previous weighing (and encoded on the card), is automatically subtracted from the gross weight and the net weight is printed beneath. When tare information is not on file, the gross weight is printed using the manual mode. The truck then must be reweighed after unloading so that the tare weight can be subtracted. Tare weights should be updated by reweighing the trucks at regular intervals. To avoid tare errors, fixed procedures should be used; for example, always weighing with half empty fuel tanks and with the driver in the truck and other personnel off the truck and scale.

Maintenance

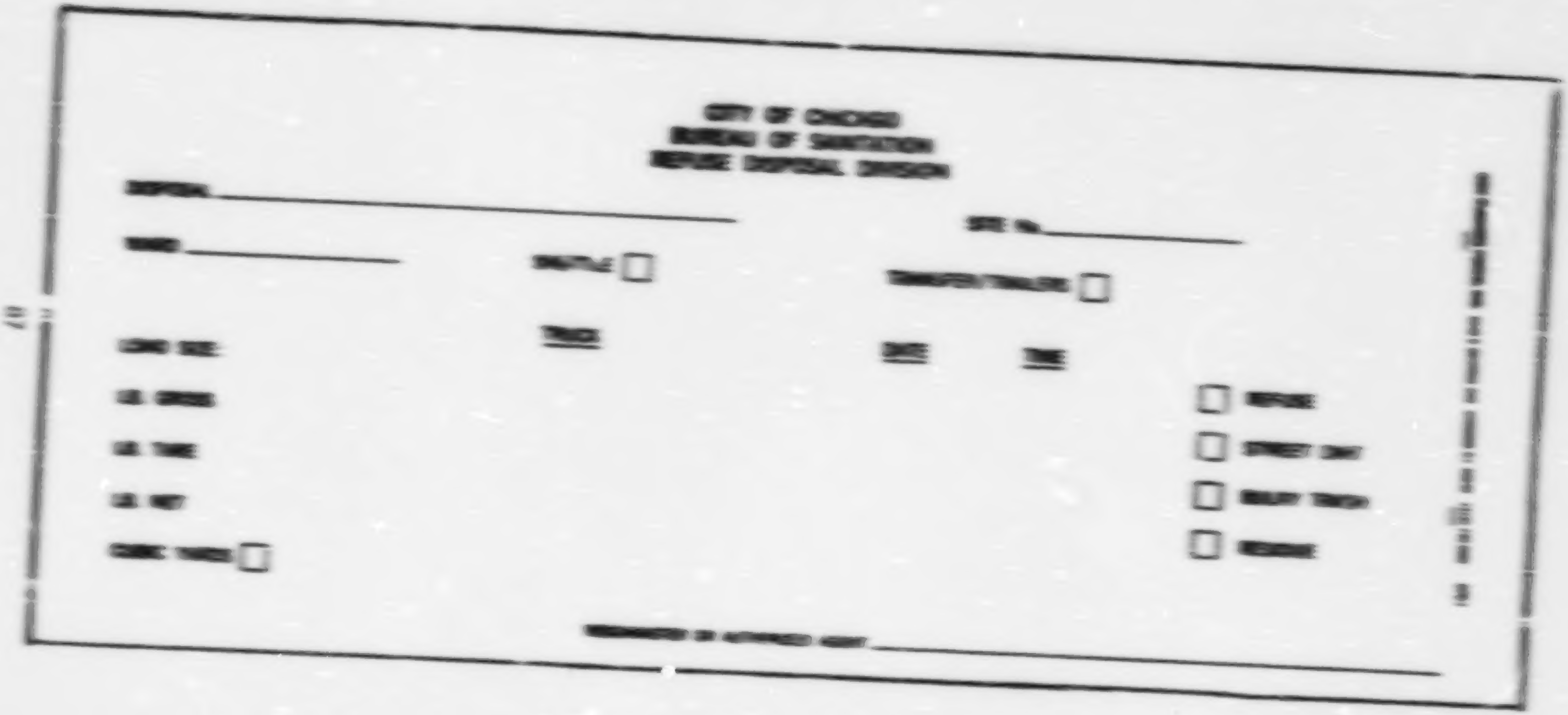
Materials used for scale platforms include concrete, steel, and wood. Concrete, which is almost maintenance-free, can be poured after scale installation is complete. One or more manholes must be provided in the platform to provide access to the scale pit.

Regular inspection and maintenance of the mechanical portion of the scale will result in better performance and longer equipment life. Adequate lighting should be provided to aid inspection and maintenance. The gap between the platform and the pit should be cleared of debris daily to prevent undue friction and subsequent weighing errors. The scale pit should be cleaned frequently and kept free of standing water. If a sump pump is used, it should be tested during each inspection.

The pivot and levers should be inspected and cleared of obstructions at three or four month intervals to insure that their functioning remains smooth without undue wear. Alignment of levers and positioning of the pivots on the bearing blocks should be checked at this time. The dial head and other electronic components should be inspected, cleaned, and adjusted by qualified personnel during inspections.

Many incinerator plants maintain inspection and repair contracts with the scale manufacturers. This procedure is not overly expensive and provides assurance that problems will be detected before major repairs become necessary. The manufacturer's capability for supplying prompt service using factory-trained repairmen is one important factor in selecting weighing equipment for a new installation.

Pivots and bearing should be cleaned and greased annually, but not less frequently than every three years. Weighbridge steel requires painting every three years. If cast iron levers are used, they are not usually repainted except during complete overhauls. Vinyl-coated steel lever systems should be inspected for damage to the protective coating and repairs made where appropriate. An electrical receptacle should be installed within a short distance of the scale platform for connection of drop lights used during inspections.



CITY OF CHICAGO
BUREAU OF SANITATION
REFUSE DISPOSAL DIVISION

DISPOSAL ____________________

WARD ____________

SHUTTLE ☐

SITE No. ____________

TRANSFER TRAILER ☐

LOAD SIZE:

TRUCK

DATE

TIME

LB. GROSS

LB. TARE

LB. NET

CUBIC YARDS ☐

☐ REFUSE

☐ STREET DIRT

☐ BULKY TRASH

☐ RESIDUE

WEIGHMASTER OR AUTHORIZED AGENT ____________________

FIGURE 12. SAMPLE WEIGHT FORM

Complete overhaul of the scale by the manufacturer may be required after 10 to 15 years of service. The cost of overhaul may be as little as $3,000. This investment is usually justified, since well-maintained scales should have a service lift of 25 to 30 years, provided that the scale pit is sound and that the scale mechanism has not sustained basic damage.

Problems

Problems encountered in the operation of scales are often related to poor maintenance, design deficiencies, obsolescence, or traffic control. Allowing dirt, water, snow, and ice to accumulate on and under the platform causes wear and rusting, hazardous driving conditions, and errors in payload.

Scales having insufficient capacity or inadequate platform length disrupt the flow of vehicles and make weighing difficult or impossible. Mechanical scales are not adaptable to the use of electronic data logging equipment. Therefore, this type of equipment becomes obsolete at the time that data handling requirements can no longer be satisfied by simple ticket printing procedures.

Disturbance of the traffic flow through the weighing station is often the result of both human and mechanical factors. Drivers may bypass the scales either intentionally or by misreading their directions. Signal lights, traffic lanes bordered by curbing, and large, plainly-lettered signs have been used to circumvent this problem. Other causes of traffic flow problems are lost or misplaced identification cards, stalled trucks, inadvertently dumped refuse requiring removal, and jamming of weight printing devices.

These problems are most serious during the confusion of peak traffic periods in the late morning and mid-afternoon. Sometimes analysis of the weigh scale records may suggest changes in starting times, pick up routes, dispatching of transfer trailers, or other expediencies which help to alleviate congestion at the peak arrival times.

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CHAPTER VIII

RECEIVING AND HANDLING SOLID WASTE

The following discussion of solid waste receiving and handling pertains primarily to incinerators. Practices for evolving thermal processing systems will be similar, except for greater emphasis on resource recovery as discussed in Chapter XVII.

Solid waste is delivered, usually during the day shifts, in several types and sizes of trucks and vehicles. The vehicles are first weighed, as discussed in Chapter VII, and then proceed to the tipping area. At large installations, the trucks unload into a storage pit, whereas at some small incinerators waste is dumped directly into the furnace charging hopper or onto the tipping floor.

Some communities attempt to segregate solid waste during collection, while others take anything that will go into a packer truck. Still others bring even furniture and large metal objects such as refrigerators, stoves, bedsprings, and bicycles to the incinerator. Sometimes commercial and industrial wastes such as large packing crates, wooden pallets, rubber tires, and spoiled batches of foodstuffs appear, or non-combustibles like concrete slabs, china sinks, or rolls of fence wire. Obviously, certain of these items should be removed by presorting, while others must be treated in some special way, such as shredding, to get them into and through the incinerator without causing damage.[1] The handling of bulky items is discussed in Chapter XVI, while components of the waste which may be removed for purposes of resource recovery of salvage are discussed in Chapter XVII.

After the wastes have been unloaded into the storage pit, the material must be transferred to the charging hopper. For incinerators with charging hoppers located above the storage pit, the transfer is usually performed by overhead cranes. Some incinerators have the charging floor on the same level as the storage area, and transferring can be done with a frontend loader or special equipment.

The solid waste is charged into the furnace by dropping it directly through a gravity chute or pushing it into the furnace with a ram. After deposition, the waste is mechanically moved through the furnace. Figure 11 is an isometric view of the solid waste receiving and handling facilities at the Chicago Northwest Incinerator.

Tipping Area

The tipping area is the flat area adjacent to the storage pit or charging hoppers where trucks maneuver into position for dumping (Figure 12). Considerations in the design of the tipping area must include adequate (1) access of trucks to the storage pit or dumping area; (2) space for uninterrupted arrival, unloading, and departure of trucks; (3) provision for floor cleanup without interference with the flow of traffic; (4) provision

CHICAGO NORTHWEST INCINERATOR
REFUSE BURNING CAPACITY 1600 TONS/DAY
WITH FOUR 400 TONS/DAY UNITS
STEAM GENERATION 110,000 LBS/HR/UNIT AT 250 PSI

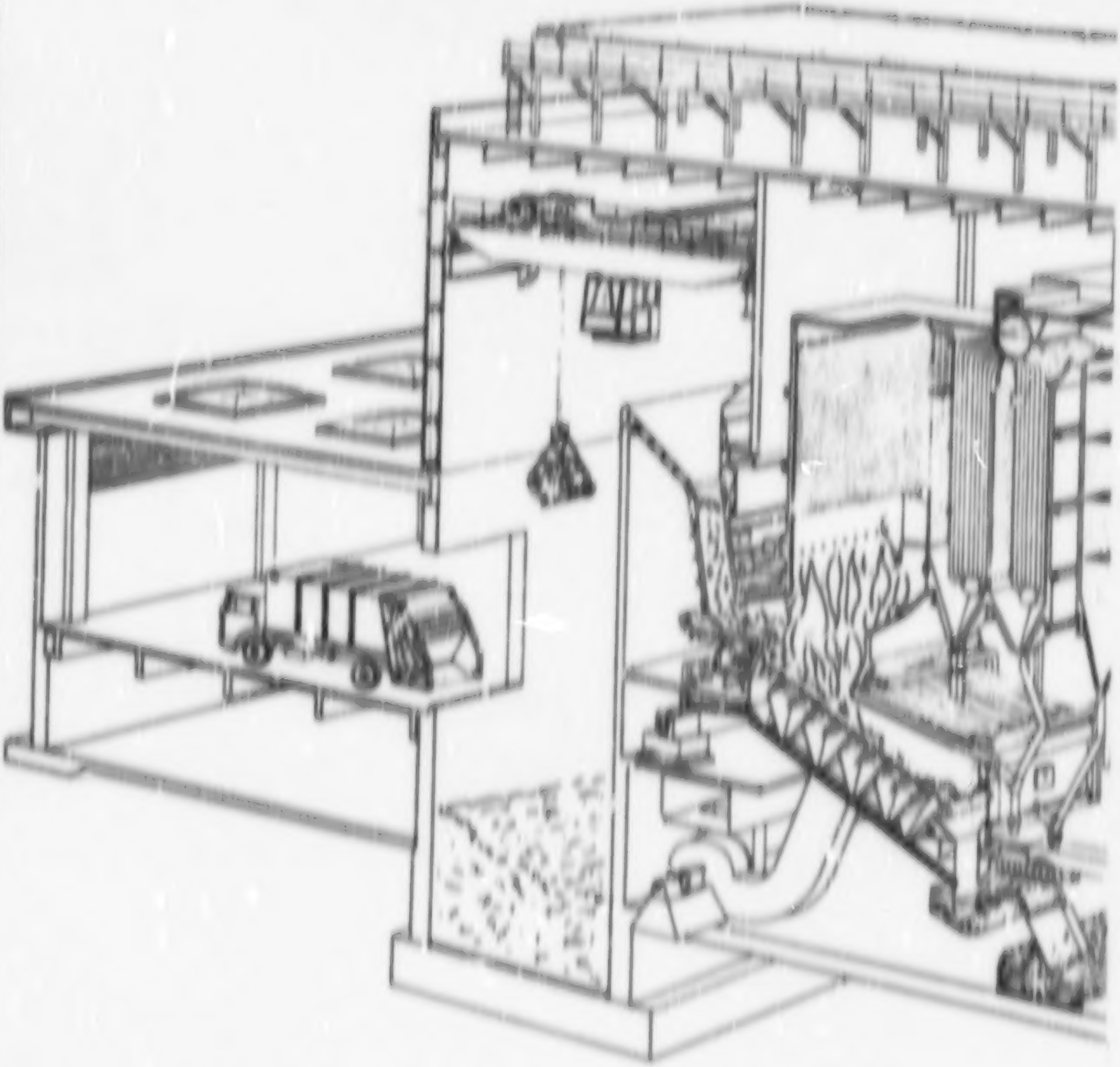

FIGURE 11.

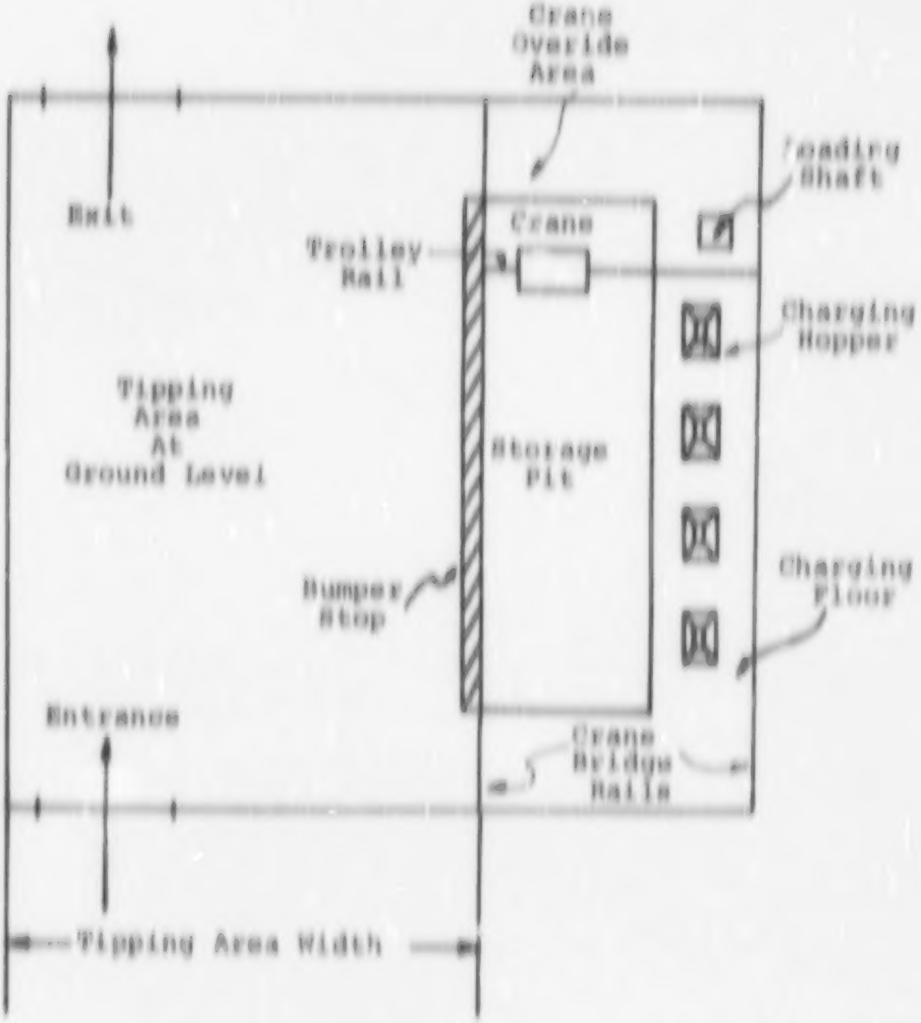
Crane Overide Area
Loading Shaft
Exit
Crane
Trolley Rail
Charging Hopper
Tipping Area At Ground Level
Storage Pit
Bumper Stop
Charging Floor
Entrance
Crane Bridge Rails
Tipping Area Width

FIGURE 12. PLAN OF TIPPING AREA AND STORAGE PITS WITH CRANE

for the safety of personnel and equipment. The area should be large enough to allow for safe and easy maneuvering and dumping, especially during times of peak traffic activity.

The receiving facilities of modern incinerators are designed primarily to accommodate packer trucks, but they must also be able to handle other types of vehicles. There are two principal types of receiving stations:

1. The floor dump, which is an open paved floor area on which the trucks deposit their loads. A tractor then pushes or lifts the refuse into conveyors or feed hoppers, or piles the waste in storage heaps for later disposition.
2. The pit dump, used in most large incinerators, which is a concrete lined pit with a curbing at one edge to which trucks can back their rear wheels and discharge the load to a level below grade, from which it is later lifted by a crane.

Dimensions. In the United States, practically all municipal solid waste is delivered to central incinerators by motor vehicles, usually in "packer" trucks of 12 to 20 cubic meter (16 to 26 cubic yard) capacity, which results in loads of three to eight tons of moderately compacted refuse. The more modern packers have means for mechanically ejecting these loads onto a level floor or into a pit, but many of the older types dump their loads by tilting the truck body so the refuse slides out the back. These are suitable for dumping (tipping) their loads into a pit, but may not eject their entire load onto a level floor unless the truck is driven forward with the body tilted. Many smaller communities, and larger communities, in emergency situations, still use standard three to five cubic yard open dump trucks for solid waste delivery. In the aggregate, there are many deliveries made by all sorts of private vehicles, ranging from the family sedan with a pail of refuse in the truck, to light trucks with crates of refuse or old furniture, and large vans loaded with special industrial wastes.

Collection trucks tend to arrive at the incinerator in large numbers during a short time interval. To avoid a backup of trucks, the length of the tipping area and storage pit must receive careful design consideration. The total length of the tipping area should extend the length of the storage pit and, if possible, beyond the pit. Width of individual dumping spaces along the pit should be about three to four meters (10 to 12 feet) and clearly marked. Support columns should not interfere with dumping spaces.

The tipping area width should be greater than the turning radii of trucks using the tipping area. For single chassis compactor trucks, the radius is between 7.6 and 10.7 meters (25 and 35 feet); for tractor trailers, the radius is between 10.7 and 15.2 meters (35 and 50 feet). The minimum recommended width of the tipping area is 50 to 70 feet; if space is available, the width should be even larger.

The entrance, exit, and ceiling of an enclosed tipping area must be high enough to provide the necessary clearance for dump trucks. Ceiling height is critical at the edge of the tipping area when the packer and dump bodies are raised in the unloading position. A minimum of 7.3 meters (24 feet) is recommended, but greater vertical clearance may be necessary for some trucks.

Vehicle entrances and exits should provide a minimum of 5.5 meters (18 feet) of vertical clearance, but greater clearance is recommended to avoid damage by the occasional truck that leaves the area with its body raised to the unloading position. A less desirable solution to this problem is to provide exit warning devices, such as hanging chains, to prevent careless drivers from attempting to exit with raised bodies. The entrance and exists should be equipped with guards to protect the door jambs.

Tipping Floor Enclosure. Enclosing the tipping area should be considered. Climatic conditions may make it desirable. In addition, an enclosed tipping area is definitely recommended for good public relations. Dust control, odor confinement, reduction of windblown refuse, noise reduction effected by enclosure, and night and weekend storage of vehicles, will make the incinerator more acceptable to the community. Even though there is much to be said in favor of enclosed tipping areas, a significant number of incinerators, in the interests of low first cost, make do with only a canopy over the tipping bays, or nothing at all.

Other Aspects of Tipping Area Design.

Floor and Drainage. The floor of the tipping area should be constructed to withstand the heavy loads placed on it, and sloped away from the storage pit toward a drain so that the area can be regularly cleaned and flushed. The floors are usually rough-surfaced for traction.

Because of the debris that accumulates in the tipping area, the drainage system must accommodate large quantities of wash water. The size of the receiving sewer is critical if the discharge is to such a system. Bar grates or other suitable devices can be used to prevent large objects from being discharged to the sewer and possibly obstructing flow.

Scattered dust and litter from the dumping, recasting, and charging operations are problems common to solid waste handling. Provisions for cleaning the tipping area should be considered during the design phase. Vacuum cleaning facilities, a compressed air system for cleaning electrical contacts, powered mobile sweepers, and flushers have been successful in controlling the spread of dust and litter.

Curb. Most plants are constructed with a curb or backing bumper along the entire length of the pit to prevent trucks from backing into the pit. This barrier must be high enough to prevent trucks from overriding, yet low enough to permit the chassis overhang to clear the curb. A height of about 30 centimeters (1 foot) is considered adequate. The face of the backing bumper is usually vertical or slightly concave to conform to the shape of the wheel. It should contain openings so that spilled waste can be shoveled or swept from the tipping floor into the pit.

The backing bumper must be durable enough to withstand repeated impact and must be securely anchored to prevent movement. In many plants the barrier has been inadequate, and redesign and replacement have frequently been required. The initial design should carefully consider the types of trucks to be used. The bumper must not only be low enough to insure clearance of the chassis, but the pit side slope and strength should take into account possible impact as the chassis opens for dumping. Breaking up of concrete is common, and steel should be considered as a basic material of construction.

Safety. Traffic control and personnel safety are important considerations with heavy trucks backing into close quarters to dump their loads. Many receiving areas attempt to provide multiple dumping areas (three to six bays usually) to handle peak delivery loading, and separate exits so the "empties" don't have to thread their way back through incoming traffic. Sometimes a special bay is reserved for cars and light trucks to keep them out of the way of the big packers.

Because of dangers involved, safety in the tipping area should be stressed by the incinerator supervisor. Hold-down chains or bumper picks are sometimes employed to prevent trucks from being tipped into the pit; however, although desirable, use of these safeguards is time consuming. Short ramps sloping away from the storage pit at an angle of 8 to 12 degrees from the horizontal will help prevent the mishaps which do occur occasionally.

Other measures to be considered for the safe operation of a tipping area are: (1) designing the tipping area, storage pit, and crane to eliminate the possibility of the crane bucket striking an extended dump body; (2) using a traffic director at larger incinerators; (3) permitting the dump bodies of packer trucks to be raised only when the truck is in the unloading space.

Storage Pit

The purpose of the storage pit is to provide a safe and convenient holding place for solid waste before it is charged to the incinerator. In a properly designed storage pit, waste from numerous sources can be mixed to provide a more uniform feed for the furnaces.

It is accepted practice to collect municipal solid waste during the daylight hours, and since collection trucks start their rounds about the same hour, and are filled about the same hour, the waste is likely to arrive at the incinerator in cycles, with two or three peak periods during the day. Where the incinerator operates more than one shift, or more days than the collection service, the waste collected must be stockpiled for burning over an extended period. Also, in case of incinerator shut-down for maintenance or repairs, or in the event of holidays, disasters or other causes of generation of large quantities of waste material, there is need for the incineration plant to accept and hold quantities of waste until it can be handled by the incinerator working at its steady capacity.

In a well designed storage pit, consideration should be given to adequate (1) storage capacity, (2) structural strength (3) design to prevent intrusion of ground water (when location is below grade) (4) drainage, (5) provision for cleanout, (6) access by crane or other unloading device, (7) protection against fire hazards, (8) suppression of dust and litter, (9) protection of operating personnel and drivers from falls and from moving vehicles and equipment.

Capacity of the Storage Pit

When the rate of receipt of solid waste exceeds the burning rate, material must be stored for future processing. The total space for storage depends upon the amount of material remaining after the daily receiving period, and the amount that is left unburned from day to day during times of peak waste delivery. The storage pit is usually designed to contain about 1.5 times the 24-hour capacity of the incinerator.

To calculate the necessary storage volume, the bulk density of solid waste in the storage pit must be known. The generally accepted average value for waste in a storage pit is about 200 kilograms per cubic meter (337 pounds per cubic yard). For example, the pit for a 19 metric ton per hour (500 ST/day) plant with provision for one full day's storage when filled up to ground level, and one and one-half day's storage with refuse piled by the crane, might be about 24 meters long, 8 meters wide, and 15 meters deep (75x25x50 feet). For a larger plant, the change would probably be mostly in increased length.

Even when travelling bridge cranes are used, the width of the storage pit does not normally exceed 9 meters (30 feet). This avoids unnecessary use of the crane for mixing and redistributing the waste prior to charging. For monorail crane installations, the minimum width is usually 5 to 6 meters (16 to 20 feet), which is wide enough to allow the crane to operate without being obstructed by the overhang of trucks in the dumping position.

If heat recovery is practiced, the pit storage capacity should receive special study to ensure a supply of solid waste adequate to meet the heat demand when waste is not delivered to the incinerator. Also, future changes in waste density should be considered when designing storage pits. This may be affected by a previous downward trend, by increased separation and recovery of paper in the home and commercial establishments, or by other local factors.

Other Aspects of Storage Pits

Shape and Construction. Storage pits are usually rectangularly shaped because of crane design and ease of construction. A rectangular pit allows the crane supports to be constructed with the use of the existing pit walls and bracing. Some pits are divided into separate rectangular units with charging hoppers between units. With this design, a fire that may start in a pit can be isolated, and pit cleaning is facilitated because of the ability to alternately empty the pits.

To provide the required strength, storage pits are usually constructed of reinforced concrete. Frequently, pit damage occurs during crane operations when the crane bucket collides with the wall and crushes the concrete.

Therefore, continuous steel plating or embedded steel T-sections in the concrete are used to protect areas of the pit subject to repeated impact.

Fires. Fires occasionally develop in the pit. They can be caused by sparks carried over by the crane during the charging operation, from live coals in the collected waste, by fires starting in parked trucks (for example, from truck hydraulic oils, gasoline, or solvent wastes), or by spontaneous combustion of stored wastes. Pit fires pose a very real danger to personnel and protection against injury is required. Many operators recommend a pit ventilation system be installed to minimize the danger of pit fires. It is claimed that exhausting air from the pit will not only assist in controlling dust and odors, but will improve safety by helping to remove smoke and heat during a pit fire.

Smoke and heat from an uncontrolled pit fire can also damage the crane, break windows, and ruin other equipment. Crane damage can put the entire plant out of operation for weeks, or even longer. Therefore, good design practice dictates that the pit be protected by an adequate sprinkler system to prevent the rapid spread of fire. Also, the pit area should be equipped with an adequate number of fire hoses of effective size and capacity.

Obviously, the walls of the pit must be built to withstand the internal pressures of solid waste and water in the pit, a condition which could occur during pit fires. The pit should be watertight and sloped to troughs and drains for dewatering. The dewatering facilities must be adequate for the expected quantities of water used during firefighting. Sumps equipped with suitable pumps help to remove excess amounts of water. Screening devices to prevent material from entering the sumps and drains are also recommended.

Groundwater. In addition to withstanding the pressure of water from within, sub-grade pits must also resist penetration by groundwater. During rainy weather, the hydrostatic pressure exerted by the water table may cause collapse of the pit walls unless they are properly designed. The walls should be of waterproof construction to prevent seepage of groundwater from "waterlogging" the refuse in the pit. Unfortunately, the problem of groundwater intrusion is common, since thermal processing facilities are often erected on otherwise marginal land which may be poorly drained or may be the site of an old refuse dump. This can lead to expensive construction of the pits, as well as expensive foundations for the rest of the structure.

Cleanout. Finally, cleanout facilities are needed to empty the pit if the furnace equipment breaks down, to remove unwanted items inadvertently unloaded into the pit, and to remove saturated waste after a fire. A loading shaft from a point on the charging floor which can be reached by the crane to the ground level is useful for unloading the pit and for hoisting heavy equipment and material from ground level to the charging floor (Figure 12).

Charging Methods

Moving the solid waste from the place it is stored to the inside of the furnace is an unusual and exacting materials handling task. The task is difficult because the material to be handled presents such broad ranges of size, shape, density, texture, hardness, slipperiness, and resilience. There is paper in all forms, from telephone books to carton boxes to greasy garbage wrappings. There is cloth, wood, pieces of metal machinery, all shapes of cans and bottles, grass and brush clippings, earth, dust, and waste foodstuffs. In good weather, the conglomerate waste (mostly paper) may be quite dry and fluffy, but during prolonged rainy spells, or in snow storms, the waste received at the incinerator may be soggy wet. The service imposed on the material handling equipment can only be classified as "severe".

A popular feeding system is comprised of a below-grade storage pit and a travelling crane with a grab bucket which lifts and carries the waste high above the furnace, and releases it into a funnel shaped hopper which leads to a chute that allows the waste to slide into the furnace under the action of gravity. Other methods include the "floor dump", which utilize bulldozers to push waste material from the charging floor into the furnace hopper, and, in other instances, various types of conveyors are used.

Whatever charging system is used, it must supply a controlled flow of waste to the furnaces while causing minimum interference with air supply for combustion, and with maximum protection against flashbacks of fire or gases through the charging opening. Besides transporting solid waste to the charging hoppers, cranes are also used to mix and distribute the solid waste in the pit. This action results in more uniform burning in the furnace and better utilization of pit capacity.

Crane Types. The types most commonly used are the monorail crane and the bridge crane (Figure 13). The former is a fixed unit suspended from a single rail that crosses the pit in only one horizontal direction. The bridge crane differs from the monorail in that it can maneuver horizontally in two directions rather than one. The capacity of the monorail crane is usually less than that of a bridge crane, and the width of the storage pit is restricted to include only that lateral area within reach of the open bucket. Capital cost of a monorail crane is less than that of a bridge crane, and at some small incinerators, its performance may be adequate.

The larger incinerators have bridge cranes in which two parallel overhead rails mutually support a cross structure, or bridge, on wheels, so the bridge can travel the length of the rails. The bridge, in turn, supports a "trolley" which suspends and operates the bucket or grapple. The bucket of the bridge crane can reach any point in the area between the support rails, and can, therefore, handle refuse in wide pits and reach furnace charging hoppers in more locations. Usually, the crane is operated by a man in a cab mounted right on the bridge or trolley, although both stationary and movable floor level control platforms have been used.

Cab design is very important, since it houses the operator whose judgment and performance in sorting and mixing solid waste and controlling the rate of feeding to the furnaces are vital to the successful operation of the incinerator. To overcome the environment of dust, odor, heat, and noise, the cabs are well ventilated, often air conditioned, and are frequently provided with communications systems.

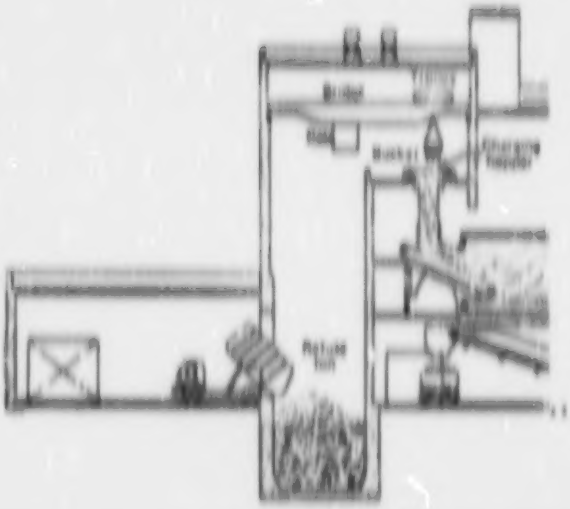
Bridge
Bucket
Charging hopper
Refuse pit

FIGURE 13. TYPICAL LAYOUT FOR SUBGRADE STORAGE PIT WITH OVERHEAD CRANE, CHARGING HOPPER AND CHUTE.[7]

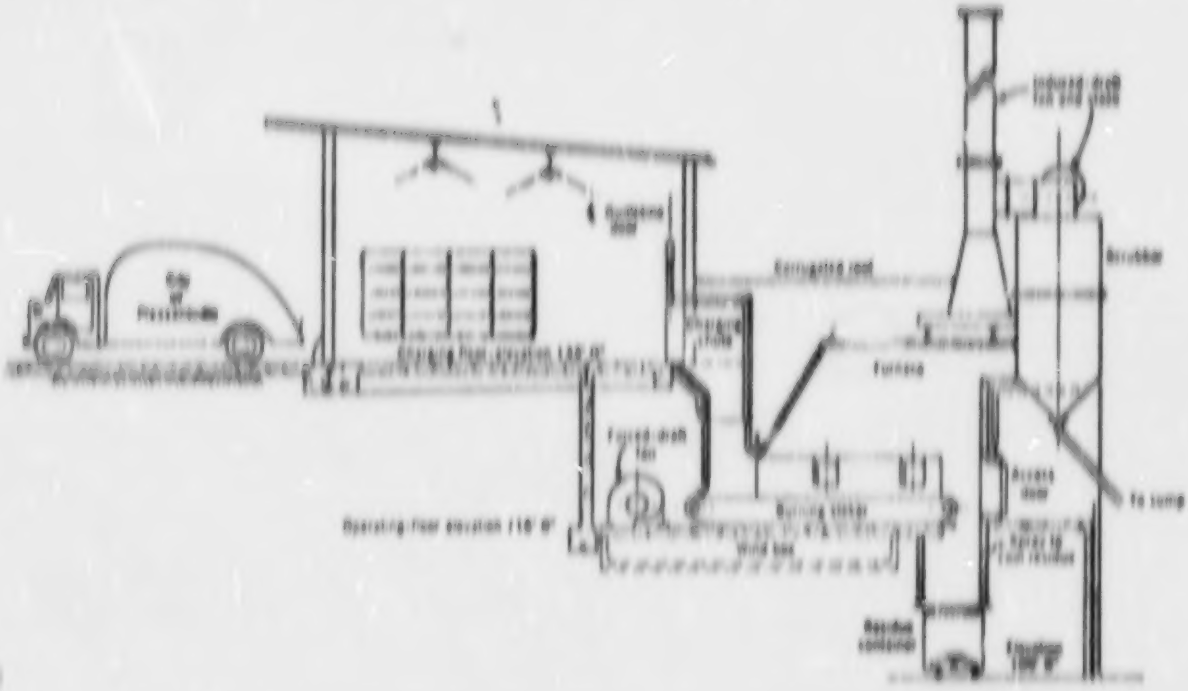
Induced draft fan and stack
Scrubber
Charging chute
Furnace
Forced-draft fan
Burning stoker
Operating floor elevation
Wind box
Access door
To sump
Residue container

FIGURE 14. TYPICAL LAYOUT FOR ABOVE GRADE STORAGE WITH SUBGRADE CHARGING CHUTE.[9]

Good cranes are costly because of the sophisticated controls, the severe duty, and the need for reliability, since a crane stoppage shuts down the entire plant. The use of two or more cranes with a total capacity of from 50 to 100 percent in excess of that required is often used to improve reliability. Special provisions are also required in the buildings which house them, such as strong, true mountings for the rails; headroom and side clearance for the trolleys and bridges; a heavy duty, well protected electrical power source to the trolley (either the "third rail" type or festooned retractable cables); and sometimes storage space for standby motors, bridges, trolleys, and buckets. A typical layout for a subgrade storage pit with overhead crane, charging hopper and chute is shown in Figure 13.

Crane Capacity and Bucket Design. Typically, the crane bucket must be large enough to "grab" 400 to 500 kilograms (882 to 1,102 pounds), about 2 to 2.5 cubic meters (2.6 to 3.3 cubic yards) of mixed refuse from the storage pit at each "bite," and to deliver its payload into the furnace charging hopper. In order to withstand the jarring, abrasive service conditions, the bucket itself may weigh five times its capacity. The crane and its drums, bearings, cables, motors, gears, and brakes, then must all be designed to lift three tons each time, and to do it continuously and reliably. Because of the punishment sustained by cranes used in refuse handling, they are most often specified as Class "E", for severe duty.[8]

The number of bucket loads that can be charged during a given period depends upon the number of cycles that the crane can make during the charging operation. A cycle is defined as the time for loading and lifting the bucket, trolleying and bridging to the charging hopper, dumping, and returning for another bucket load. Typical cycles vary from 1-1/2 to 3 minutes. To determine the cycle time, the hoisting, bridging, and trolleying speeds must be known, as well as the length, width, and depth of storage pit. Typical hoisting and trolley speeds are between 76 and 92 meters per minute (250 and 300 ft/min), whereas bridge travel speeds may be as high as 107 meters per minute (350 ft/min).

Incinerator cranes ordinarily use the closed scoop bucket or a grapple. The closed scoop is a clamshell with heavy steel lips, usually equipped with short teeth to increase penetrating ability. The grapple type is similar to a clamshell but has much longer teeth, called tines, and has a considerably larger capacity than a similar closed scooped bucket. The grapple is a poor cleanup tool because of the length and spacing of its tines. For cleaning purposes, the grapple can be equipped with bolted-on pans.

Number of Cranes. Crane downtime will stop incinerator operation unless a standby crane is provided. Nearly all installations with a capacity above 15 metric tons per hour have a second crane to prevent shutdown. A second crane is recommended wherever possible, certainly for plants with capacities exceeding 10 metric tons per hour and operating 24 hours per day. Because of high costs, most small plants have only one crane. At larger installations, a third crane is often justified. With a second or third crane, space in addition to the operating space required for the first crane must be provided for the storage of the units when not in service. The point of storage for the nonoperating unit(s) must not interfere with the operating unit.

Control and Operation. The crane can be operated manually from a cab travelling with the crane, or from a remote fixed operating point. Manual operation from a mobile cab is most common and thought to have some advantage over a remote fixed operating point since the operator has better visibility. However, a remote fixed cab can be used successfully. Where the pit is long, the distance judgment error is reduced with mobile cab operation. When a mobile cab is used, the operator should have a safe convenient boarding platform. Since the charging operation may be dusty and hot, the crane cab should be air-conditioned.

At least one large incinerator plant utilizes a travelling bridge crane which employs an automatic, load cell type device for weighing the contents of the bucket. With this device, the bucket weight can be observed by the crane operator as required or can be automatically recorded. When automatic weighing equipment is provided, weighings are made when the bucket is at rest, usually when it reaches the top of the vertical travel, and only at periodic intervals.

Discussion of Other Charging Methods. Another charging method, used in some smaller incinerators, utilizes a handling floor upon which the trucks discharge the refuse. The "floor dump" consists of a concrete or bituminous surfaced floor sheltered or enclosed by a simple structure. A bulldozer equipped with a lift bucket is used to move and pile the solid waste on the floor, sometimes ten feet high, until it is fed into the incinerators. The sides of the enclosure are constructed to withstand the side thrusts of the waste piles, and there are sewers for drainage and often sprinklers and ventilation systems to cope with dust, fire, and odor. A typical layout of above grade storage with a subgrade charging chute is shown in Figure 14.

Tractors with bulldozing blades and lifting buckets used with the floor dump charging method are simpler and less costly than travelling cranes. However, they can only be used to feed a furnace hopper where the waste does not have to be taken out of a below-grade pit, and lifted above the furnace. If the tipping floor is at an elevated level with respect to the furnace, as is possible with a hillside location or with a man-made ramp, the tractor operator can mix, sort and feed refuse to a bank of incinerators just as efficiently as a crane operator, and, in case of a breakdown, the machine can be quickly replaced with another tractor, or even, temporarily, with a snowplow on a truck.

Continuous chain, bucket, or belt type conveyors are sometimes used in feeding incinerator furnaces. However, mechanical difficulties are common with this type of equipment, and provision must be made to deal with the possibility of a disabled conveyor buried under tons of solid waste.

Charging Hoppers

Charging hoppers are used to maintain a supply of solid waste to the furnace. In batch-feed furnaces, a gate separates the charging hopper from the furnace and supports the solid waste while the furnace is burning the previous charge. Generally, one hopper is provided for each furnace cell.

In a continuous-feed furnace, the waste-filled hopper and chute assist in maintaining an air seal to the furnace as well as providing a continuous supply of solid waste. Most charging hoppers have the shape of an inverted, truncated pyramid. The size of the hopper opening depends somewhat upon the size of the furnace, but it should be large enough to prevent arching of oversized material across the hopper bottom. Common hopper openings measure from 1x2x1.2 meters to 1x2x2.4 meters (4x4 ft to 4x8 ft). The hopper should be deep enough to receive a bucketfull of solid waste without spilling over.

The charging hopper is generally steel and sometimes concrete lined. Because of abrasion from solid waste, impact from the crane bucket, and heat from the furnace, the hopper must be constructed of rugged material and built to facilitate repair and replacement. The hopper is often equipped with a sliding charging door at the throat, or with metal covers which can be quickly applied to seal them off, in case of fire burning back from the furnace.

Charging Chutes

The charging chute connects the hopper to the furnace and may be nearly as wide as the furnace so that the solid waste will pass through the chute without clogging. The discharge of waste into the furnace is usually by gravity, but reciprocating or vibrating feed mechanisms may also be used.

The chute is usually made of smooth temperature-resistant metal extending several feet down from the "throat" of the hopper into the furnace, and terminating above one end of the stoker or hearth. The resultant column of waste forms an air seal, and the lower end of the column is exposed to the heat of the furnace for drying and ignition. The stoking action starts the ignited material on its way through the furnace, and new waste from the column replaces it. The "buffer" quantity of waste in the chute and hopper permits the actual feed rate into the furnace to be controlled by the stoker action and allows the crane to be used for stacking refuse or feeding other furnaces for reasonable intervals of time.

The end of the chute in the furnace is usually water cooled or lined with refractory or concrete. The welds which fasten the cooling jackets to the chute may cause difficulties when the two metals differ in composition or when frequent overheating occurs.

An innovation to the gravity fed chute has been the addition of an hydraulically activated horizontal ram at the bottom of the chute to push "slugs" of mixed waste into the furnace. This affords positive control of the feed rate and serves as the chute seal in place of the charging gate. The ram is arranged so as to push a load of waste onto an exposed drying and ignition hearth, and in the next stroke, the new load tumbles the dried refuse over a parapet onto the actual stoker.

Charging Methods for Evolving Thermal Processing Systems

The trend in newer system designs is to shred municipal solid waste prior to thermal processing. This added step is a necessary adjunct to resource recovery systems, as discussed in Chapter XVII, and allows mechanical or pneumatic conveying to be used in place of the usual cranes.

For example, suspension fired incinerators require shredding, usually to less than 5 centimeters in size. This is true whether the refuse is to be fired with coal in a conventional boiler, or in fluidized bed or suspension fired boilers especially designed for municipal solid waste.

Some pyrolysis processes can handle as-received municipal solid waste, but pyrolysis processes in which residence time is short, such as in flash pyrolysis, must be fed solid waste reduced in size. When pyrolysis liquids and solids for fuel use are principal products, shredding and separation of non-combustibles prior to pyrolysis is necessary to avoid high ash contents in the fuel. Therefore, the feed systems in such processes are based on handling finely divided material, for example pneumatic transport of minus 24 mesh preprocessed solid waste.

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CHAPTER IX

DESIGN OF INCINERATOR FURNACE SYSTEMS

The incinerator furnace system serves the following functions:

1. Charging the waste to the combustion zone at a controlled rate.
2. Drying the waste sufficiently to permit ignition of combustibles.
3. Burning the waste to essentially inert solid residue and flue gases with a minimum of polluting constituents.
4. Dissipating the heat of combustion.
5. Collecting, cooling, and removal of solid residues.

Receiving and handling of the municipal solid waste, including charging methods, proper disposal of effluents, process control, and recovery of energy are covered in other chapters.

Fundamentals of Solid Waste Incineration

Incineration with air can be thought of as occurring in three overlapping stages which may take place in different sectors of the furnace. First, heat from the combustion process is used to drive moisture from external and internal surfaces; second, the solids are further heated causing physical and chemical changes, sometimes called pyrolysis; and third, oxygen in the air reacts with combustible materials both in the solid itself and driven from the solid during pyrolysis, emitting large quantities of heat. Proper incinerator furnace design requires that adequate residence time, temperature, and turbulence be provided for each stage of combustion to insure contact of oxygen with the combustible materials under conditions where combustion is essentially complete.

As shown in Table 25, the primary combustible elements in refuse are carbon and hydrogen, with much lower but significant amounts of sulfur and nitrogen. Some constituents of the ash may also oxidize during incineration. The net result of effective combustion is the conversion of the carbon in the trash to carbon dioxide (CO_2) and hydrogen to water (H_2O). Sulfur is converted to sulfur oxides (primarily SO_2), some nitrogen is converted to nitrogen oxides, and organic chlorides are converted to hydrogen chloride (HCl). These latter compounds, along with particulate emissions, constitute potential air pollutants which are discussed in Chapter XIV. Combustion at 760 to 980 C (1400 to 1796 F) will normally produce a sterile residue and an effluent gas free of odors, assuming adequate furnace design, and operations which do not exceed design feed rate.

The air supplied to the incinerator has several important functions. It supplies the oxygen necessary for combustion; it carries combustion products

Table 25

TYPICAL MUNICIPAL SOLID WASTE

CATEGORY	WEIGHT % (as fired)*	COMPONENT	WEIGHT %
Metal	8.7	Moisture (H_2O)	28.16
Paper	44.2	Carbon (C)	25.62
Plastics	1.2		
Leather and Rubber	1.7	Oxygen (O)	21.21
Textiles	2.3	Hydrogen (H)	3.45
Wood	2.5	Sulfur (S)	0.10
Food Waste	16.6	Nitrogen (N)	0.64
Yard Waste	12.6	Ash	20.82
Glass	8.5		
Miscellaneous	1.7		
	100.0		100.00

*This weight distribution shows the effects of moisture transfer between the categories in the refuse during storage and handling. For example, the food waste tends to lose moisture and the paper absorbs moisture. Gross heating value 2375 calories/gram (4275 BTU/lb).

and vaporized water from the incinerator; and finally, the air and the resulting flue gas absorb heat from the combustion reactions and carry it from the combustion zone. Air may also be used to aid in establishing turbulent conditions in the furnace and in cooling vital furnace elements.

The quantity of air supplied to the incinerator furnace is a major determinant as to the size of the equipment. In incinerators without heat recovery in the combustion zone, the quantity of air is determined by the requirement for heat removal. For example, as shown in Table 26, the air required to maintain the incinerator at about 800 to 1100 C (1472 to 1990 F) is two to three times that theoretically necessary for complete combustion, or 6.4 to 9.6 tons of air per ton of refuse. To reduce this air requirement, one must either extract heat, as in the water wall steam recovery incinerator to be discussed in Chapter X; or operate at a high temperature where ash tends to fuse into a slag, thus the slagging type incinerator which has been under development.

Drying and Ignition of Refuse

Much of the material in mixed solid waste has loosely bound or surface moisture which is readily vaporized when heat is applied, leaving the burnable material too cool to volatilize and ignite until most of the water has been driven off. To perform the drying function and to prevent smothering a going fire with undried and non-combustible material, most furnaces have some provision for exposing newly charged material to radiant heat energy and hot gases to drive off and absorb the moisture. As previously mentioned, these provisions take the form of exposure at the bottom of a feed chute or on a drying stoker or hearth, or brief suspension in hot gas as the refuse falls onto the stoker.

After the moisture has been driven off, the heat radiated to the refuse by the hot gases and hot surfaces, and conveyed to the refuse by the motion of hot gases, increases the temperature of the refuse until combustibles pyrolyze, vaporize, and begin to combine with oxygen. This is the ignition process which starts the burning. In most furnaces, the original ignition at startup is done by a match, torch, or pilot burner, but thereafter the burning material ignites the incoming waste. Design features, like positioning of grates with respect to heat reflecting walls, or guiding of flame gases over the incoming wastes, are employed to ensure ignition. In some furnaces, to ensure ignition when there are unusually wet loads, auxiliary gas or oil burners are positioned to direct their flames on the incoming refuse.

During the drying and ignition phases of incineration, there are large quantities of steam and gases liberated, expanding to many times their original volume. Therefore, furnace designs provide for unrestricted flow of these gases away from the generation zones, so that fresh air can get in to supply oxygen and prevent smothering of the flame.

The Combustion Furnace

The heart of the incineration system is the combustion furnace, which consists of a chamber to contain the reaction, a stoker to transport solid

Table 26

COMPARISON OF ADIABATIC FLAME TEMPERATURES FOR COMBUSTION OF A TYPICAL SOLID WASTE WITH VARYING AMOUNTS OF EXCESS AIR*

Percent excess Air	0	50	100	200	300
Air Requirement, tons per ton refuse	3.21	4.82	6.42	9.63	12.84
Flue Gas, tons per ton refuse	4.03	5.64	7.24	10.45	13.66
Adiabatic Flame temperature, °C	1660	1343	1088	793	638
(°F)	(3020)	(2449)	(1990)	(1459)	(1180)

*Based on approximately 2750 calories/gram gross heating value (4950 BTU/lb).

waste through the furnace and agitate it to expose new surface to oxygen and heat, and air supply to furnish oxygen for combustion, and a pressure differential (draft) to cause air to enter and the gaseous products of combustion to flow out of the chamber.

Configuration. Of the many furnace shapes and sizes, common configurations include the upright cylindrical (Figure 15), the rectangular (Figure 16), the multi-chamber rectangular (Figure 17), and the rotary kiln following a rectangular furnace (Figure 18).

The cylindrical furnace is usually refractory lined. Solid waste is charged through a door or lid in the upper part (usually the ceiling) and drops onto a central cone grate and the surrounding circular grate. Underfire forced air is the primary combustion air and also serves to cool the grates. As the cone and arms rotate slowly, the fuel bed is agitated and the residue works to the sides where it is discharged, manually or mechanically, through a dumping grate on the periphery of the stationary circular grate. Stoking doors are provided for manual agitation and assistance in residue dumping if required. Overfire air is usually introduced to the upper portion of the circular chamber. A secondary combustion chamber is adjacent to the circular chamber. As far as is known, no cylindrical furnaces have been built in the United States in recent years.

The multicell rectangular type may be refractory lined or water cooled. It contains two or more cells set side-by-side, and each cell normally has rectangular grates. Solid waste is usually charged through a door in the top of each cell. Generally the cells of the furnace have a common secondary combustion chamber and share a residue disposal hopper.

The rectangular furnace is the most common form in recently constructed municipal incinerators. Several grate systems are adaptable to this form. Commonly, two or more grates are arranged in tiers so that the moving solid waste is agitated as it drops from one level to the next level. Each furnace has only one charging chute.

A rotary kiln furnace consists of a slowly revolving inclined kiln that follows a rectangular furnace where drying and partial burning occurs. The partially burned waste is fed by the grates into the kiln where cascading action exposes unburned material for combustion. Final combustion of the combustible gases and suspended combustible particulates occurs in the mixing chamber beyond the kiln discharge. The residue falls from the end of the kiln into a quenching trough.

Except for the rotary kiln, the furnaces are generally constructed on concrete foundations with either a structural steel framework supporting inner walls and a roof arch of refractory material (supported wall and suspended arch construction), or typical masonry with bricks laid one atop another (gravity walls) and self supporting arched roofs made of keystone shaped bricks (spring arches). The supported wall and suspended arch are almost universally used in modern incinerators. Metal or refractory hooks secure the refractory to the structural steel, and a layer of insulation and an outer sheet metal

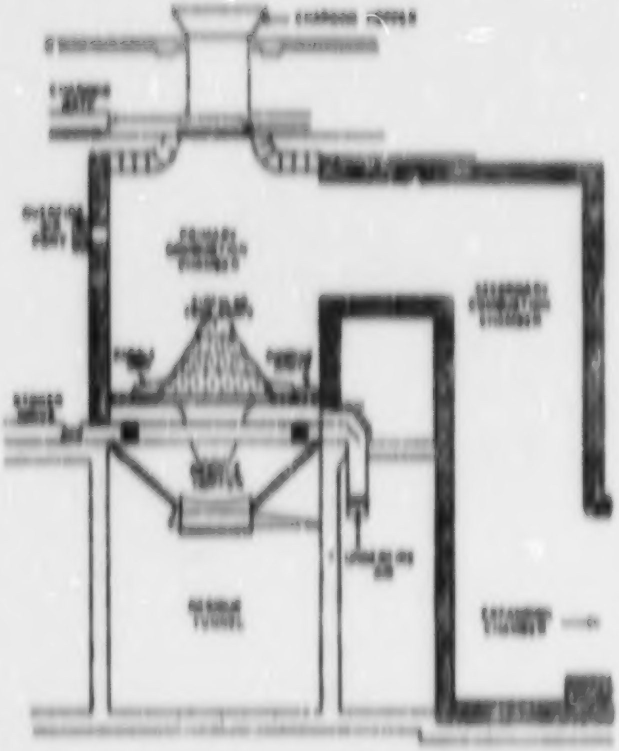


FIGURE 15. UPRIGHT CYLINDRICAL FURNACE[1]

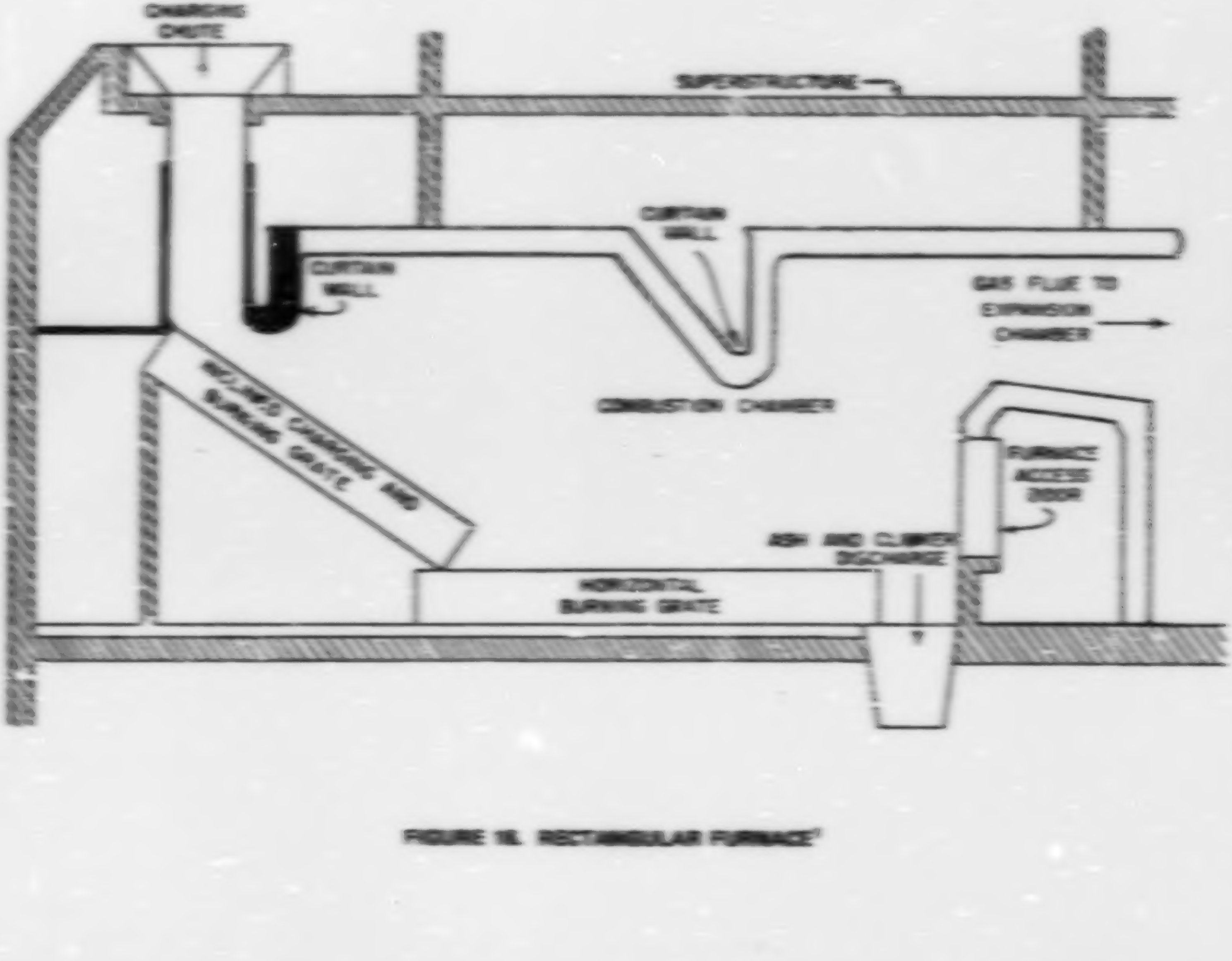

CHARGING CHUTE
SUPERSTRUCTURE
CURTAIN WALL
CURTAIN WALL
GAS FLUE TO EXPANSION CHAMBER
COMBUSTION CHAMBER
INCLINED CHARGING AND BURNING GRATE
FURNACE ACCESS DOOR
ASH AND CLINKER DISCHARGE
HORIZONTAL BURNING GRATE

FIGURE 16. RECTANGULAR FURNACE[7]

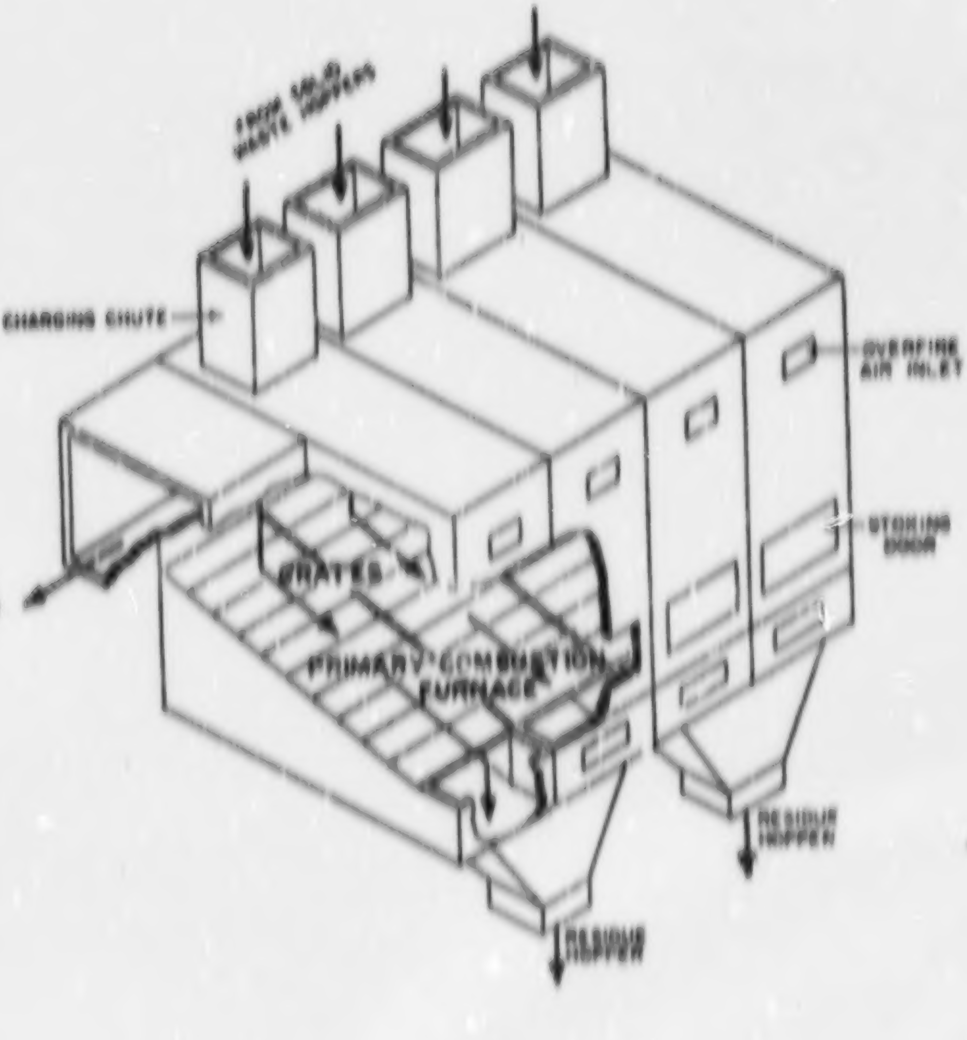

FROM SOLID WASTE HOPPERS
CHARGING CHUTE
OVERFIRE AIR INLET
STOKING DOOR
TO SECONDARY COMBUSTION CHAMBER
GRATES
PRIMARY COMBUSTION FURNACE
RESIDUE HOPPER
RESIDUE HOPPER

FIGURE 17. MULTICHAMBER RECTANGULAR FURNACE[1]

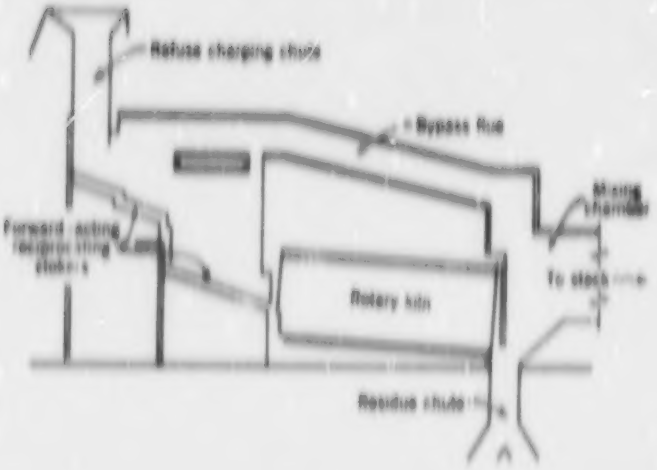

Refuse charging chute
Bypass flue
Mixing chamber
Forward acting reciprocating stokers
Rotary kiln
To stack
Residue chute

FIGURE 18. ROTARY KILN FURNACE[1]

casing usually complete the wall structure. Water wall construction is discussed in Chapter X, "Recovery and Utilization of Energy."

Secondary combustion zones provided in incinerators are chambers connected by passages from the primary combustion chamber, but seldom sharply defined. Rather, they tend to be extensions or enlargements of the primary chambers, sometimes set off by half walls or baffles that cause the gases to flow in turbulent eddies for a time long enough to complete the combustion process.

The size of the various furnace zones and openings is usually determined by the manufacturer according to his experience for gas flow rate and residence time; solids flow rate, depth, and residency time; avoiding obstruction due to the inadvertent admission of oversize objects; heat release; and other mechanical considerations. A few typical parameters for furnace volume and grate area determination are provided in Table 26. These parameters may be expected to vary by as much as 10 percent.

Refractory. Four different forms of refractory are used; fired refractory bricks, which are laid up with a very thin layer of refractory cement between bricks; plastic refractory which is supplied in a damp clay-like consistency and is spread and pounded into place against lath or hooks; ramming mixes which are usually machine rammed into place in wet form (resulting in higher density than plastic refractory); and castable refractory which is poured into temporary molds, like concrete.

The latter three forms are usually dried out at low furnace heat and then assume their final vitreous strength when the furnace is brought up to its normal operating temperature.

There are many compositions of refractory material, usually clays of silica or alumina. These are called fire clays and are used in various grades for varying conditions of heat, erosion, and chemical resistance. Special high performance refractories may be used in certain areas of the furnace where unusually severe conditions are encountered, such as high temperature and erosion, e.g. in furnace linings at the edges of the stoker bed. For example, silicon carbide brick is often used in side walls near the moving grate for resistance to erosion and slag attack, and mullite or other special refractories may be selected for resistance to spalling in charging areas. Summaries of refractory properties and placement are available,[9] but refractory manufacturers should be consulted prior to specification.

Grates and Stokers. In practically all municipal incinerators, except rotary kilns, the refuse rests on grates while burning. These grates are, in general, metal surfaces with holes or slots through which underfire combustion air enters. Usually the grates are movable by mechanical means, so they can move the refuse through the furnace, agitate the refuse to promote combustion, and remove the ash and residue from the furnace. These mechanical grate systems are called stokers, since they perform the function which used to be done by men who tended the fire using long metal hoes and stoking bars. Many furnaces are still equipped with doors in the sides through which manual stoking can be done when necessary.

Upright cylindrical furnaces have a floor of dumping grates above the ash pit. These grates are pivoted on axles, so that when they are rocked large spaces open up for residue to fall through. Above the floor of the grates, mounted on a vertical axis, is a star shaped rabble arm which rotates slowly and spreads and tumbles the refuse on the grate during combustion. In these furnaces, new batches of refuse are dumped in from the top at intervals, and they are, therefore, classed as batch type furnaces.

The flow-through furnaces are equipped with stokers which receive solid waste at one end and continuously move it horizontally and downward through the furnace, finally depositing the residue in a receiver at the opposite end of the furnace. During the journey through the furnace, the refuse is supplied with underfire air which comes up through the grates from a windbox under the stoker. Fine particles of ash (siftings) fall through the holes in the stoker surface and must be caught and removed to avoid eventually clogging the windbox and the grate openings.

There are at least six principal types of flat-bed stokers available:

1. The travelling grate stoker, which is essentially a moving chain belt carried on sprockets and covered with separated small metal pieces called keys. The entire top surface acts as a grate while moving through the furnace, yet can flex over the sprocket wheels at the end of the furnace, return under the furnace, and re-enter the furnace over a sprocket wheel at the front. The sprockets drive this chain conveyer, and are in turn driven by electric motors at slow speed (Figure 19).

2. The reciprocating grate stoker, which is a bed of bars or plates arranged so that alternate pieces, or rows of pieces, reciprocate slowly in a horizontal sliding mode over the stationary pieces and act to push the refuse along the stoker surface. These are driven through links by electric motors or hydraulic cylinders (Figure 20). An adjustable grate knife action may be added to the last portion of grate to split refuse lumps and to knock ash from clinkers in order to improve burnout (Figure 21). The double reciprocating stoker uses two movable grates sandwiching a stationary grate (Figure 22).

3. The reverse reciprocating stoker is an inclined reciprocating grate stoker in which the reciprocating action is opposite to the gravitational flow of the solids. A continuously rotating motion of the refuse bed is created, drawing burning refuse underneath, and burning incoming refuse from the bottom up (Figure 23).

4. The rocking grate stoker is a bed of bars or plates on axles. By rocking the axles in a coordinated manner, the refuse is lifted and advanced along a surface of the grate. The stoker is actuated by linkage driven by electric motors or hydraulically (Figure 24).

5. In the vibrating stoker, grates with overlapping edges are vibrated by an electrically operated eccentric drive assembly mounted on a shaft, resulting in a conveying action toward the discharge point (Figure 25).

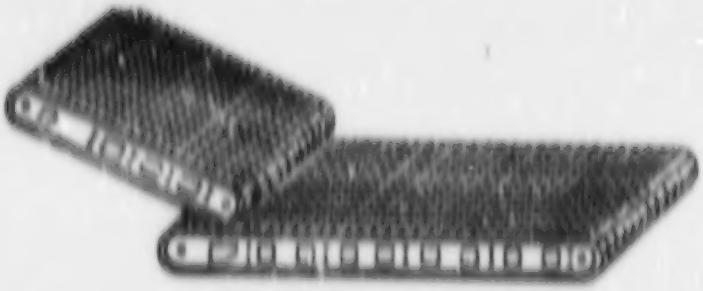


FIGURE 19. TRAVELING GRATES[1]

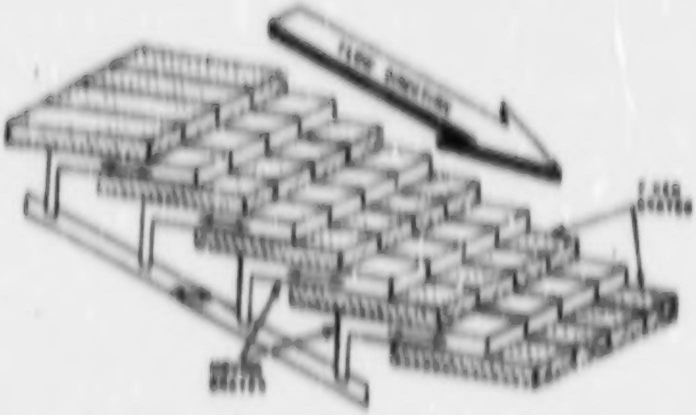
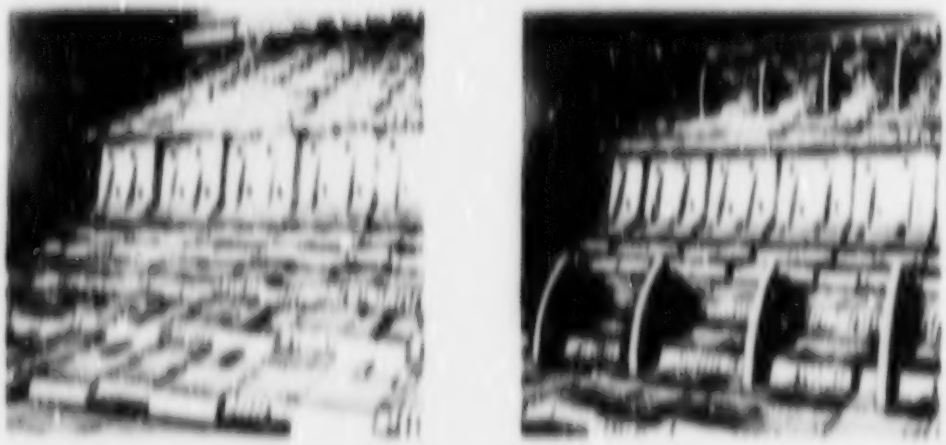


FIGURE 20. RECIPROCATING GRATES[1]



grate construction showing knives in raised position at right

FIGURE 21. GRATES WITH KNIFE ACTION

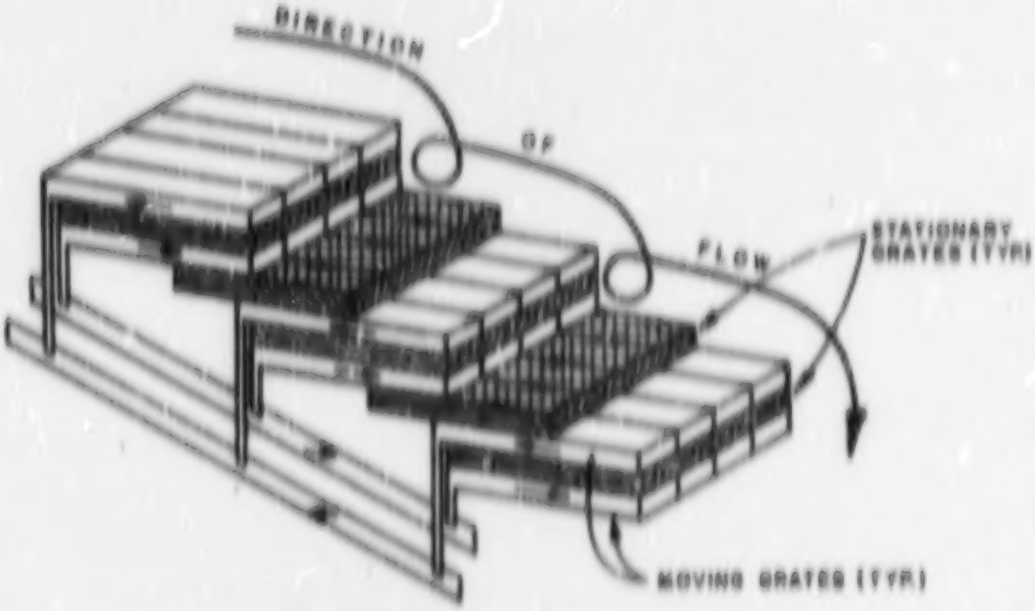

DIRECTION
OF
FLOW
STATIONARY GRATES (TYP.)
MOVING GRATES (TYP.)

FIGURE 22. DOUBLE RECIPROCATING STOKER

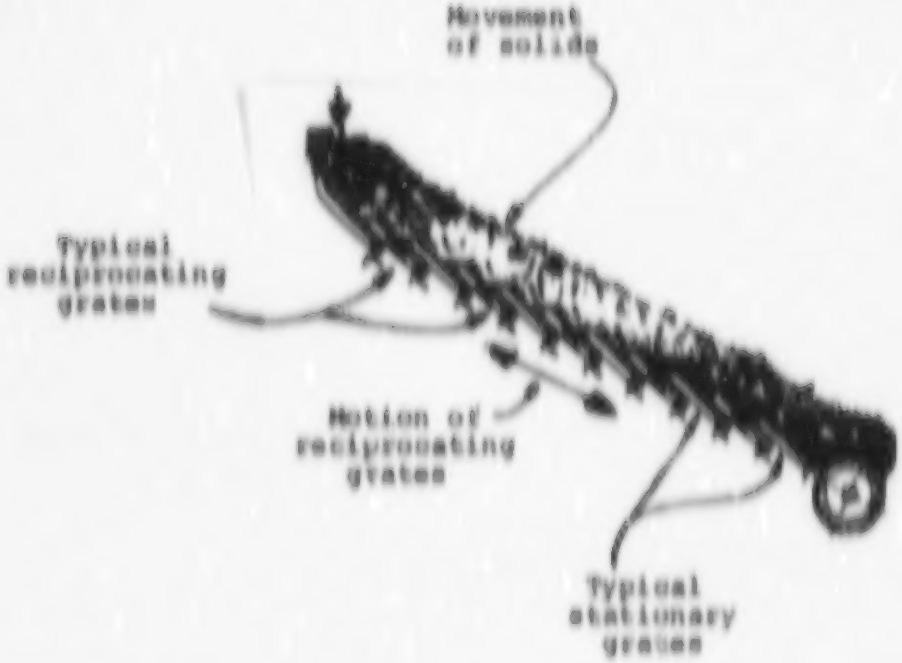

Movement of solids
Typical reciprocating grates
Motion of reciprocating grates
Typical stationary grates

FIGURE 23. GRATE BAR ACTION IN REVERSE RECIPROCATING STOKER (ALSO SHOWN IS THE ASH DISCHARGE ROLLER)

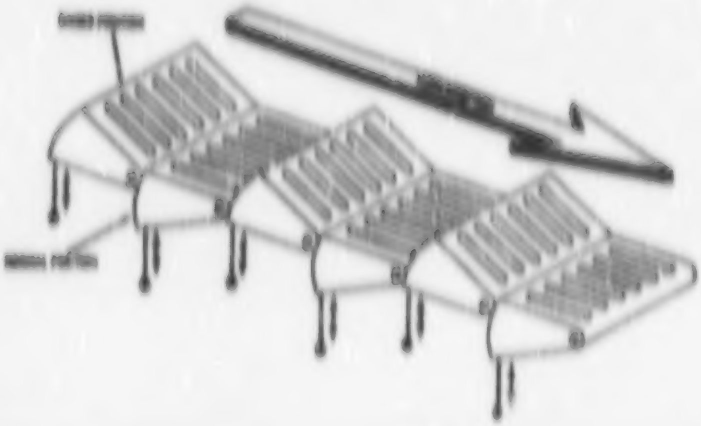


FIGURE 24. ROCKING GRATES[1]

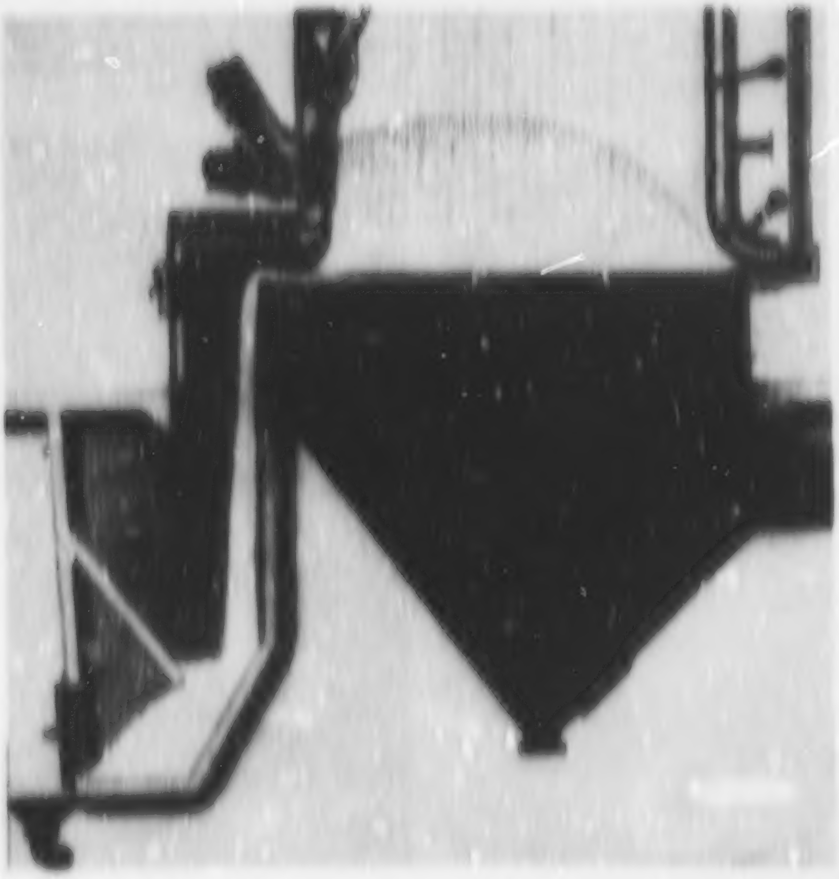


FIGURE 25. VIBRATING CONVEYING GRATE STOKER

d. The inertial grate stoker is constructed as a fixed bed of plates with the entire bed carried on rollers. The stoker is activated by an electrically driven mechanical drive which draws the bed slowly back against a spring, and then releases it so that the entire bed moves forward until stopped abruptly by another spring. The inertia of the refuse carries it a small distance forward along the stoker surface and then the cycle is repeated.

Flat-bed stokers may be horizontal or inclined down in the direction of flow, and may be used as a single stoker or as a series of two or three units arranged in stair-step array, so the refuse is tumbled and agitated as it moves from one section to the next. Often the individual sections can be operated so as to advance the refuse at different speeds to control drying and burn-out (Figure 26).

In the roller grate (Figure 27), the solid waste is fed onto the first roller, and then progresses by the action of the slowly rotating rollers to the ash discharge point. The revolving rollers disturb, agitate, and reorient the bed so that the new burning surfaces are constantly exposed, assisting in complete combustion.

The grate surfaces are made of sturdy iron or steel castings, alloyed and designed to resist distortion, growth, cracking, and oxidation. However, in well designed furnaces, the grate surfaces do not characteristically operate at temperatures even near that of the fire because they are protected by unignited refuse, by ash, and by the cooling underfire air passing through them. In the drying and ignition zones, the volatile combustible gases, water vapor, and smoke are driven off and flow into the secondary combustion chamber where they are mixed with air and retained long enough to complete combustion. After the ignition zone of the stoker, the residual refuse burns off its fixed carbon with a clean hot flame which radiates heat energy to facilitate the proper burning of the still-combustible gases and airborne particulate matter.

Rotary Kiln. The rotary kiln (Figure 10) is really a combination furnace and stoker and is effective in gently tumbling the burning refuse until complete combustion is achieved. The kiln is a large metal cylinder with its axis horizontal or slightly inclined. It is lined with firebrick and mounted on rollers so that electric motors can slowly rotate it about its horizontal axis. As used in municipal incinerators, the refuse is first passed over drying and ignition stokers in a furnace, and then, when most moisture and volatile constituents have been driven off, the burning residue is fed into the kiln for final burnout. In such an arrangement, the volatiles driven off in the ignition chamber are led through a passage above the rotating kiln and join the hot gas effluent from the kiln in a secondary combustion chamber, where the oxidation of the combustible gases and combustible airborne particulate matter is completed.

Bulky Objects. A few cities have recently built a specialized type of incinerator for burning logs, heavy brush, and bulky objects like discarded furniture (Chapter XVI). This has taken the form of a large box-like furnace with typical furnace wall refractory and insulation construction, and large doors at one end. The floor is a simple firebrick hearth and one end of the furnace is

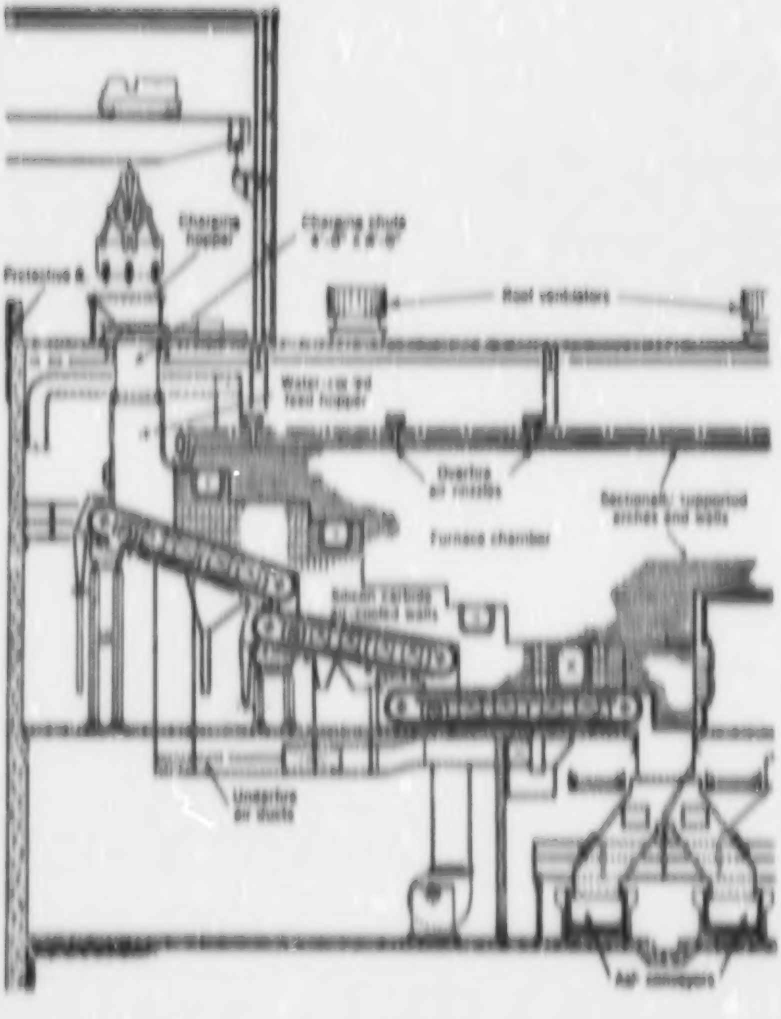

Charging hopper
Charging chute 4'-0" x 4'-0"
Protective &
Roof ventilators
Water-cooled feed hopper
Overfire air nozzles
Sectionally supported arches and walls
Furnace chamber
Silicon carbide air cooled walls
Underfire air ducts
Ash conveyors

FIGURE 26. THREE-STOKER INCINERATOR[3]

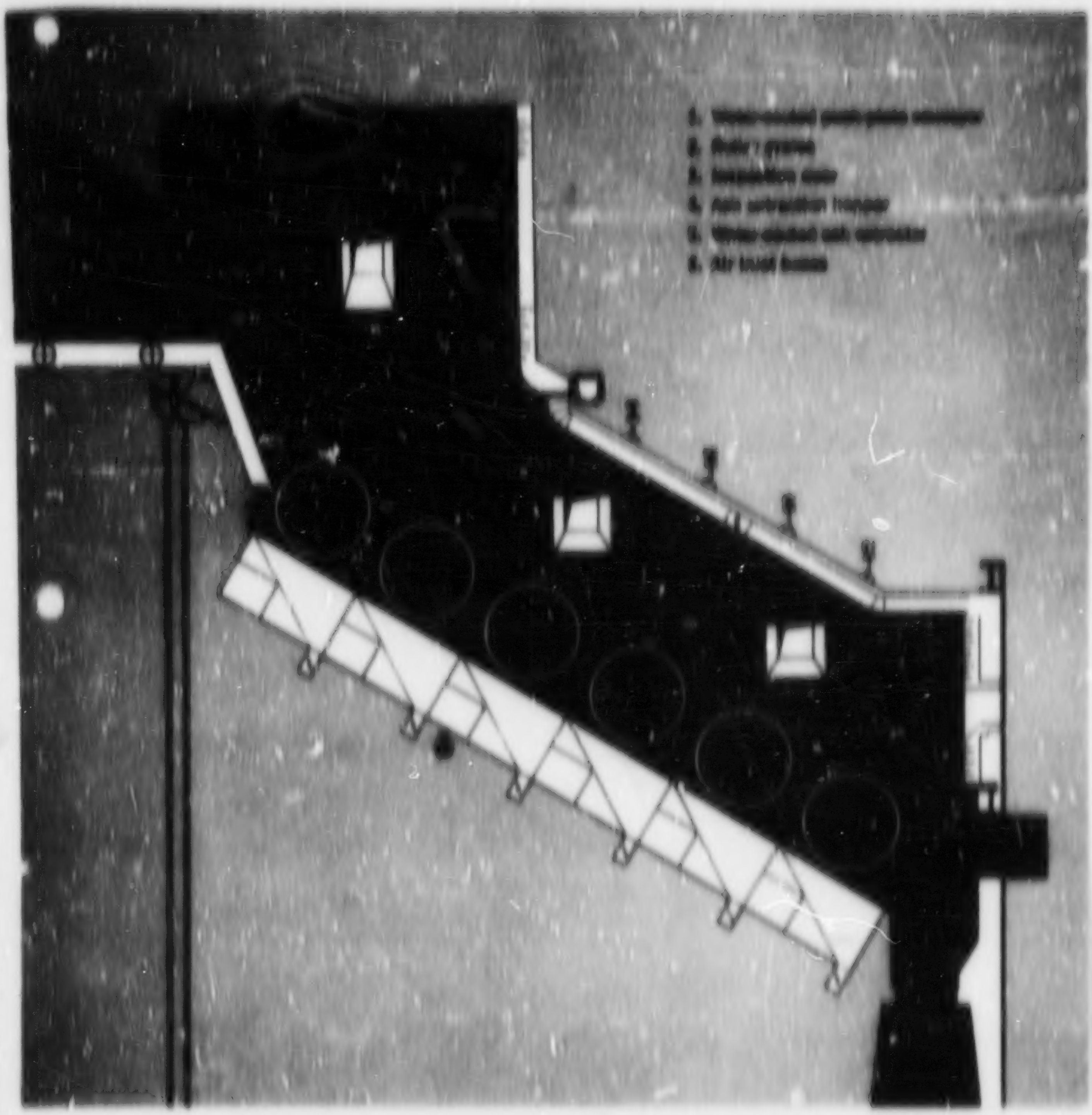

1. Water-cooled push-plate [illegible]
2. Roller grates
3. Inspection door
4. Ash extraction hopper
5. Water-sealed ash extractor
6. Air inlet boxes

FIGURE 27. ROLLER GRATE

constructed to collect the flue gases and treat them in a cleaning process before release to the atmosphere. The bulky refuse is pushed into the furnace by a bulldozer, ignited, and allowed to burn down to a residual ash, which is cleaned out of the incinerator by the bulldozer when the furnace has cooled. Combustion conditions in such a furnace vary with time, complicating the problem of air pollution control. Shredding is another approach to the handling of bulky objects discussed in Chapter XVI.

Air Flow. In constrast to the underfire air which enters the furnace through and around the grates, air which enters the furnace above the grates through the sides or roof of the furnace is called overfire air. Overfire air is used to mix with and burn the combustible gases driven off from the refuse. Overfire air is usually introduced in high velocity jets at specific points which vary with furnace design, and is directed so as to provide turbulence and thorough mixing of the gases for optimum combustion. As discussed earlier, total air flow in excess of that required for combustion is used to cool the burning gases to temperatures which will permit reasonable furnace life.

The flow of air and other gases through a furnace is caused by forcing air in and/or drawing gases out so that atmospheric air flows in through openings provided. The most common arrangement in modern furnaces uses forced draft fans for underfire air and overfire air jets, in conjunction with an induced draft fan for flue gas removal.

Furnace pressures are usually held slightly below atmospheric pressure so that if doors are opened, or if there are any leaks in the walls, atmospheric air will be drawn into the furnace, rather than permitting the hot, odorous and sometimes dangerous gases to flow out of the furnace to the surrounding workspace. This "negative pressure" is maintained by drawing out slightly more gas than the air and the gases that are positively blown in or generated in the furnace. Natural draft, utilizing a tall stack or chimney, has been the traditional way to develop a "negative pressure." The heated gases in the stack are less dense than the cooler atmospheric air outside the stack and so tend to flow upward, drawing additional gases behind them.

Stacks are popular because they are simple and can be constructed to handle the large volumes of hot and corrosive gases (e.g. containing small quantities of sulfur oxides and hydrogen chloride). Also, they discharge the airborne products of combustion high into the atmosphere to aid dispersion. After the first cost of erection, stacks require no further expense for power and usually need only nominal maintenance. However, there are practical limitations on height and cost, which limit the amount of suction available to draw the flue gases through efficient dust collection devices. For these reasons, the newer incinerators do include induced draft fans ahead of the stack to provide the degree of suction required for efficient air pollution control devices.

Induced draft fans, while usually much less costly initially than a natural draft stack, do have important limitations. They have limited tolerance to high temperatures and to corrosive conditions such as can be caused by condensation of acid gases, and they are susceptible to erosion by flyash. Therefore, gases are normally cooled and cleaned, including demisting where applicable, prior to the fan.

Induced draft fans are large and require large drivers which use considerable power. These are usually electric motors, but can be steam turbines. Depending on dispersal requirements, fans can exhaust into very tall stacks or relatively short lightly constructed stacks. Sometimes provision is made for varying the fan speed to control the gas flow through the furnace, but more often dampers are used for this control.

Temperature. The temperatures in a well operated modern municipal incinerator furnace are controlled between reasonably close limits to obtain consistently effective combustion. Since the incoming solid waste varies in composition, e.g. moisture content, good temperature control requires automatic control methods, as discussed in Chapter XII. Average temperatures in the burning fuel bed on the grates, and just above, may reach 1100 to 1400 C (2012 to 2552 F). The temperature of the flaming gases falls from this level to about 650 to 900 C (1202 to 1652 F) as the gases flow through the primary and secondary combustion chambers. Generally the gas temperature is kept above 760 C (1400 F) to ensure oxidation of all malodorous compounds, and below 980 C (1796 F) to prolong the furnace life.

Dissipating the Heat of Combustion

Early incinerators, which had to burn solid waste of low heating value, were designed primarily to conserve and reflect the heat of combustion so as to dry and ignite the refuse and heat the resultant gases above the deodorizing temperature with minimum use of supplementary fuel. Hot flue gases were discharged directly through masonary stacks with refractory linings, with a "settling chamber" at the base and a "spark screen" at the top as the air pollution control. Early attempts to use "waste heat" from the combustion chamber to generate steam were unsatisfactory because there was relatively little "waste heat." Furnace walls were designed to conserve as much heat as possible.

Modern municipal incinerators, burning refuse of much higher heating value, and emitting their flue gases through sophisticated air pollution control devices, are designed to dissipate the heat of combustion, so that after achieving the temperature necessary for complete combustion in the furnace, the flue gases are cooled to as low as 250 C (482 F) before they enter air pollution control systems.

With either water wall or refractory furnaces, a waste heat boiler, an array of tubes in the path of the hot gases (convection section) in which steam is formed by vaporizing water, can bring the flue gases down to 300 C (572 F) and even lower. This reduces both the gas volume and temperature, making possible the use of more economically sized exhaust fans and electrostatic precipitators, or other air pollution control devices. Heat of combustion is thus transferred to steam, and the energy is made available to do work, as discussed in Chapter X.

The two most common methods of reducing the flue gas temperatures are by dilution with ambient air and by evaporation of water directly into the gas stream. In addition, there is always some direct conduction and radiation of heat through the walls of the furnace and ducting. Direct admission of air is a simple and easily controllable operation. A damper in the ducting allows outside air to be drawn into the flue gases because the draft of the chimney or of the induced draft fan causes a lower pressure inside the gas ducts than outside. However, even though cooling the flue gases decreases their volume, the amount of fresh air added increases the net volume so that larger and thus more costly ducts, fans, air pollution control equipment and stacks are required.

If water is mixed with, or exposed to the hot flue gas stream, the water tends to evaporate, and in so doing absorbs heat from the gas. In round numbers, the evaporation of one kilogram (2.2 lbs) of water can lower the temperature of 10 kilograms (22 lbs) of hot gas by 240 C (432 F). Although increased in weight, the total volume or the cooled gas and the steam is less than the volume of the original hot gas, so smaller fans, ducts, and pollution control equipment can be utilized. However, if the evaporative cooling system is not designed for complete water evaporation, the water absorbs sulfur and chlorine compounds from the flue gases, becomes acidic, and attacks the structure of the gas cleaning equipment unless specially designed to resist corrosion. Often, water neutralization is practiced and water quenching is combined with a wet scrubber for gas cleaning, since the water supply, distribution, and containment systems can be used in common. This will be discussed in Chapter XIV.

The quenching and scrubbing water may be introduced as sprays, on wet baffles, which are obstructions placed in the gas duct with water flowing in thin films over the structure; or as wet bottoms, which are simply shallow water tanks which form the bottom sections of the flue gas ducting. The effectiveness of evaporative cooling is usually dependent upon good mixing of the gas and liquid. Complete evaporation, i.e. leaving no water residue, requires sophisticated nozzle design and control systems.

Collecting, Cooling and Removal of Residual Solids

Solid residue is generated at three places in a municipal incinerator: unburned residue conveyed through the furnace by stoker; the siftings that fall through grate openings; and the fly ash collected from the flue gas. An additional source of residual solids in some incinerators is material removed from internal walls and other areas during shutdown for cleaning and maintenance. Since, on average, 20 to 25 percent of the weight of municipal mixed refuse is glass, rock, cans, and other metals and minerals, the collection, cooling, and removal of the non-combustible solid residue is a significant materials handling task. Fortunately, as discussed in Chapter I, solid residue should comprise less than 10 percent of the average volume fed into a properly performing incinerator.

Stoker Residue. The principal incinerator residue is that discharged from the stoker. This consists of broken glass and ceramics, metal cans of all shapes and sizes, stones, earth, assorted hardware, and some fused ash (clinkers) from melted glass, metals and minerals, all surrounded by flakes and dust of the light fluffy ash that typically results from burning paper or wood. Although some incinerators do a remarkably thorough and consistent job of burning the combustibles, insufficient residence time and varying refuse characteristics in other incinerators permit some incompletely burned material to appear in the stoker residue.

Telephone books, catalogs, and heavy bundles of newspaper, particularly if wet, are not readily penetrated by air for direct combustion, or by radiant or convective heat for drying and volatilization, so it is not uncommon to even find unburned paper in residues. Heavy timbers or green wood may pass through the burning cycle with a core of unburned wood still present. Certain foodstuffs containing high water content and occurring in thick sections, like watermelon rinds, carrots, apples or waste meats may char on the outside and seal in liquids, thus permitting some putrescible material to appear. All this may be aggravated by operating an incinerator at maximum feed rate to handle a peak load, instead of slowing the stoker to permit better drying and longer combustion time for difficult wastes. Nevertheless, a typical "good" residue contains less than 5 percent by weight of unburned carbon and less than 1 percent of putrescible organic material. Shredding of bulky wastes aids in obtaining good "burnout."

Large incinerators with flow-through furnaces generally use conveyer systems to remove the stoker ash (Figure 28). The residue is usually discharged from the stoker grates into a water filled trough where it is thoroughly quenched and cooled. It is usually conveyed from the quench system to elevated storage hoppers, from which the residue can be discharged directly to trucks underneath the hoppers.

Residue Conveyors. Removal of residue from the quench trough is commonly accomplished by a metal drag link conveyor. This consists of a pair of endless metal chains with metal bars attached between the chains, like a rope ladder, driven by an electric motor through sprocket wheels to drag along the bottom of the ash trough and capture the residue, pull it out of the trough, up a chute, and into a waiting bin or truck. These drag link conveyors are heavily constructed of heat resistant cast steel drag link parts, with corrosion resistant metal or concrete tanks and chutes for containing and guiding the wet, abrasive residue. They travel slowly, thus allowing water to drain back into the tank from residue moving up an inclined chute. The unused portion of the drag linked chain, which is returning from the point of discharge of the residue back to the entrance to the quenching tank, may require as much supporting, guiding, and protective structure as the working section of the chain.

It is common practice to position drag link conveyor paths transversely across the discharge ends of two or more rectangular furnaces so that the residue of both can be carried to a common discharge point for economy of overall structure and material of the conveyor. Because the residue removal conveyors are such vital elements of the incineration system, and because they are big, heavy, and somewhat difficult to service, they are often built in parallel pairs with a diverting chute so that each of several furnaces can direct its residue to each of two residue conveyors to ensure reliable service.

Another type of conveyor system is a metal mesh travelling belt on which the residue falls from the stoker, and is spray quenched. Other systems, using metal apron-type conveyors, vibrating conveyors, and rubber belts for cooled residue are in use, but the metal drag link type is the most popular. Manual handling of residue has practically disappeared, except for a few small older incinerators.

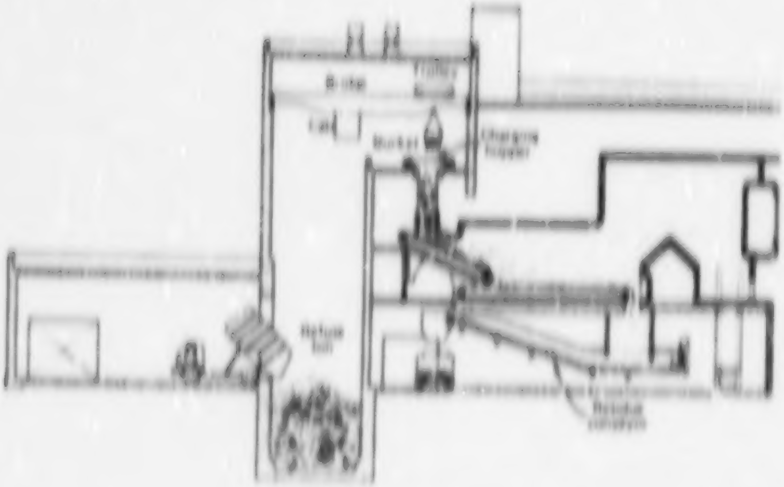

Bridge
Trolley
Cab
Bucket
Charging hopper
Refuse bin
Residue conveyor

FIGURE 26. RESIDUE DISPOSAL FROM CONTINUOUS-FEED FURNACE BY INCLINED, WATER-SEALED CONVEYOR[7]

Metal Salvage. A few incinerators have equipment for separation of residue and salvage of metal, mostly tin cans. The separation is usually done in a metal drum or barrel with holes in its sides and mounted to rotate about its horizontal axis. This tumbles the residue and the ash falls through into a hopper, while the cans finally pass out the end of the drum to another hopper. Sometimes magnetic separators are used to collect the steel from the rest of the residue. The cans are usually pressed flat or shredded to make them into salable scrap, either at the incinerator site or by a dealer. The non-metallic ash is a dense, inert material, almost like a damp earth, and is sometimes sold for road fill.

Grate Siftings. The siftings are dust-like bits of ash, often still glowing, that drop through the grate openings and cover whatever is below. They sometimes contain an appreciable percentage of combustible and putrescible matter. The amount varies with the type of stoker and the material being burned. Certain types of plastics that melt, or greases that can run through the grate openings, may accumulate in the underfire air chambers and ignite and burn, unless precautions are taken.

Some stokers rely on manual cleanout of siftings through doors provided for the purpose. Others provide hoppers under the grates and means ranging from mechanical and pneumatic conveyors to water sluicing to move the accumulated siftings either to an outside collection point, or onto the quenching tank with the other solid residue.

Siftings and stoker residue removal can be combined in a "wet bottom" furnace in which the entire furnace foundation is made as a concrete basin which is filled with water. A drag link conveyor as wide as the furnace runs the entire length of the furnace and drags out the grate siftings which have fallen into the water, as well as the stoker residue which falls into the quench water at one end of the foundation.

Flyash. Flyash in a municipal incinerator is the particulate matter which is light enough to be carried out of the furnace by the existing gas stream. Dust, ash, fine burning particles, and even sizable pieces of burnt or burning paper are released from the grate by underfire air and fuel bed agitation, so that about 10 to 20 percent of the weight of the ash in the solid waste charged into the furnace leaves as airborne flyash.[4] Modern air pollution control devices, described in Chapter XIV, are usually designed to collect 95 or more percent of this flyash, either by dry collection in hoppers or by capturing it in water. The flyash is conveyed by mechanical or pneumatic conveyors, or by sluicing with intermittent floods of water through pipes, either to a storage hopper for truck loading, or to the quenching tank for removal with the other solid residue.

Residue, siftings, and flyash suspended in water can be recovered in settling tanks or lagoons. Further discussion of this topic is included in Chapter XIII.

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CHAPTER X

RECOVERY AND UTILIZATION OF ENERGY

While common in Europe, the conversion of solid waste to energy in the United States was until recently only an interesting idea reduced to practice in a very few plants, most using specially designed incinerators to produce steam. However, the recent awareness of an "energy crisis" has spurred no less than twenty cities to consider projects for steam generation by prepared refuse combustion, many using existing fossil-fuel fired steam boilers. The feasibility of this approach has been shown in a project partially supported by the U.S. Environmental Protection Agency. Most of the following discussion deals with incinerators specially designed for steam production. The use of prepared refuse to supplement coal or other fuels is dealt with specifically in a later section of this Chapter.

Energy Recovery Systems vs Refractory Incinerators

Non-energy recovery incinerators have refractory combustion chambers, while combustion chambers in steam-producing incinerators are usually water tube wall construction. The choice between burning refuse in refractory incinerators or providing for energy recovery is generally not clear cut. Advantages and disadvantages of both approaches are compared in Table 27.

Pyrolysis provides another alternative for energy recovery in the form of fuels. Pyrolysis processes which produce liquid fuels are particularly attractive, from the point of view of energy recovery, because of the ease with which this form of energy can be stored.

Generally, energy recovery systems cost more to install and operate, present more operating difficulties and safety considerations, and put the municipality into a business, but do provide significant credits from the sale of the steam. It should be noted that steam is not a storable commodity, and major customers should be contracted before a project is justified by the steam credits. Major investments are required for generation and distribution systems.

To illustrate the potential for energy recovery, steam production in several recently designed installations is shown in Table 28. For a given incinerator, the amount of steam generated is primarily a function of the combustible content of the refuse, as shown in Table 29.

Energy Uses

It should be noted that the primary purpose of a thermal processing facility is to dispose of municipal solid waste. This waste never stops coming. Therefore, any complications which tend to reduce reliability must be carefully evaluated. Both in-plant use and export of steam should be considered, as well as the use of steam turbines to generate electric power, although

Table 27

COMPARISON OF REFRACTORY INCINERATORS AND ENERGY RECOVERY SYSTEMS

Refractory Incinerators	Energy Recovery Systems
1. High excess air required to control furnace temperature	1. Moderate excess air
2. Large refractory combustion chamber to handle high gas flow	2. Moderate size combustion chamber, but requires water tube wall construction, and may require additional parallel lines for steam supply reliability
3. Costly furnace auxiliary equipment due to high gas flow, including FD and ID fans, air pollution control equipment, ducts, and stack.	3. Furnace auxiliary equipment similar to refractory incinerators, but less costly due to lower gas flow.
4. No steam facilities required	4. Requires expensive steam facilities and controls, including water tube walls, waste heat boiler, boiler feedwater treating, soot blowers, steam condensers, and steam distribution
5. Requires flue gas cooling system such as spray chamber (waste heat boiler sometimes used)	5. Waste heat boiler producing steam used for cooling
6. Relatively simple operating procedures	6. Operations complicated by necessity to meet steam supply demands, maintenance of steam equipment, presence of high pressure steam systems, etc.
7. Moderate potential for corrosion, especially in air pollution control equipment	7. Possible steam tube corrosion and erosion require monitoring and additional maintenance cost; air pollution control equipment corrosion can be problem as with refractory incinerators.
8. Moderate operating costs	8. Higher operating costs because of increased complexity.

Table 27 (Cont'd)

Refractory Incinerators	Energy Recovery Systems
9. Only possible byproduct credits are for pre or post incineration salvage	9. Considerable steam credits possible in addition to salvage, including in-plant use of steam for fan drives, heating, etc.

Table 28

EXAMPLES OF REPORTED STEAM GENERATION QUANTITIES[3]

	System 1	System 2	System 3	System 4
Solid Waste Type	A	B	A	A
Steam Temperature, °C (°F)	327 (620)	205 (401)	260 (500)	241 (465)
Steam Pressure, atm abs. (psig)	28.2 (400)	18.0 (250)	16.3 (225)	18.7 (260)
Steam Production, tons/ton refuse*	3.6	4.3	1.4-3.0	1.5-4.3†

* Tons steam per ton of refuse fed to the furnace varies with refuse heating value, as shown in Table 29.

† See Table 29 for variation of steam production w/heating value.

A Solid waste as received.

B Solid waste prepared by shredding and partial metal removal.

Table 29

EFFECT OF SOLID WASTE HEATING VALUE ON STEAM PRODUCTION

Nominal Refuse Heating Value, cal/g. (BTU/lb.)	3611 (6500)	3333 (6000)	2778 (5000)	2222 (4000)	1667 (3000)
Refuse, % Moisture	15	18	25	32	39
% Noncombustible	14	16	20	24	28
% Combustible	71	66	55	44	33
	100	100	100	100	100
Steam Generated, tons/ton refuse*	4.3	3.9	3.2	2.3	1.6

* These values are calculated for a specific operating incinerator, but they are believed to truly reflect actual results.

the latter is not now a significant method for energy recovery in the United States. As will be described, air conditioning can also be exported.

In-Plant Uses. The most obvious and efficient use of the energy recovered is in the thermal processing plant itself. Power plants, oil refineries, and chemical and other large manufacturing facilities have long practiced "energy recycle" in order to keep the overall utility (i.e., fuel, water, electricity) costs to a minimum.

Steam turbines to drive induced and forced draft fans, large pumps, and other significant power requirements provide a major outlet for recovered energy. Other uses include space heating, snow and ice melting from ramps, and tracing to prevent freezing of water lines. One steam generating incinerator estimates its steam usage as tabulated in Table 30.

All the energy requirements of the plant are not usually supplied by the steam. Steam driven equipment has a higher capital cost; therefore the steam is not "free." Backup electric driven equipment must be provided to startup fans and other equipment when steam is not available. Weather protection, heating, and other services must be provided, even when steam generating facilities are not operating. Obviously, the necessary backup equipment adds to capital costs. Figure 29 depicts an example of an in-plant steam distribution scheme.

In-plant usage of steam is a straightforward method of utilizing up to about half of the energy available from combustion of the solid waste. No capital cost is required for external steam distribution, and the complexity of matching steam supply to export demand is avoided.

Steam Export. Because of the projected energy shortages and ever-rising fuel costs, the economic picture has begun to favor generation and sale of energy produced from solid waste. This is illustrated by the simple "fuel equivalent" comparison made in Table 31.

However, it cannot be emphasized enough that these "favorable economics" can be illusory. No credits will accrue if the energy cannot be sold. Much, if not most of the steam produced in the U.S. solid waste incinerators is being condensed because of the lack of customers.

Steam generated can be used directly for heating purposes. Typically, the steam pressure as generated is in the 18 to 45 atm. (250 to 650 psig) range. If low pressure steam, for example 11 atm. (150 psig), can be sold for space heating, the pressure difference between the high and low pressure steam can be utilized to drive in-plant non-condensing turbines prior to entering the distribution systems. The use of steam for heating may require both steam distribution and condensate return lines. If the customer is distant, the condensate return line may be eliminated, but this increases the cost of boiler feedwater treating.

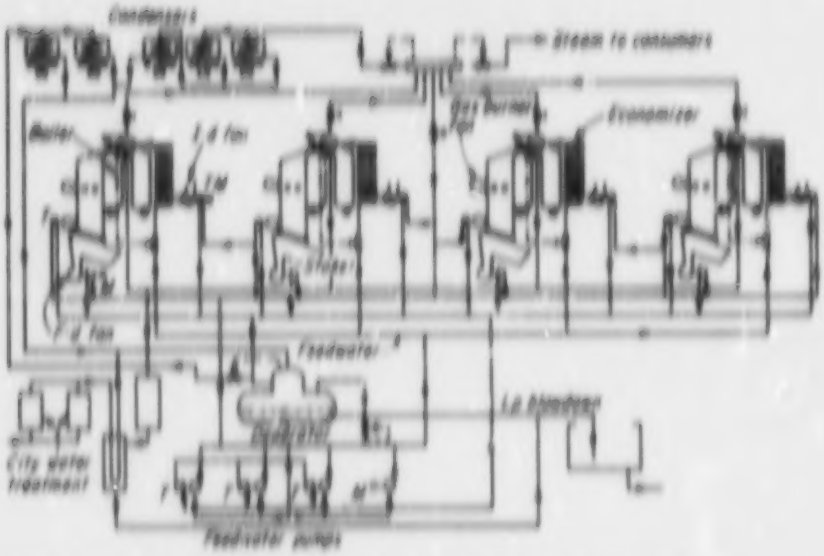
Table 30

EXAMPLE OF IN-PLANT USAGE OF STEAM*

Fans	25.3 % of total steam generated
Feedwater pumps	5.1
Feedwater heater	2.1
Space heating	5.3
Water heating	2.7
Condenser protection against freezing	6.1
Total in-plant usage	46.6
Maximum available for sale	53.4

* Calculated from reference 5.

FIGURE 28[9]


Condensers
Steam to consumers
Boiler
I.d fan
Fan
Gas burner fan
Economizer
Stoker
F.d fan
Feedwater
City water treatment
Deaerator
Lp blowdown
T
T
M
Feedwater pumps

Auxiliary equipment of the four combinations of incinerators and boilers in Chicago is steam turbine driven, except for the electric motors needed to start the plant when no steam is available. Note use of air cooled condensers

T=steam turbine
M=electric motor

Table 31

COMPARISON OF RELATIVE VALUES OF REFUSE AND FUEL OIL BASED ON HEATS OF COMBUSTION

Crude Oil Price, $/barrel	3.50	7.00	10.00	15.00
Equivalent "Value" of Refuse $/metric ton*	6.80	13.61	19.44	29.16

* Based on 42 gallons of oil per barrel, 0.9 specific gravity, 10,000 calories per gram (18,000 BTU/lb); and refuse at 2778 calories per gram (5000 BTU/lb)

Obviously this type of arrangement creates a responsibility for the municipality to reliably deliver the steam, the failure of which may have drastic consequences. Therefore, the use of auxiliary burners fired by fossil fuel and/or an auxiliary fossil fuel fired package boiler is required to meet demands during downtime of the thermal processing facility, during periods of wet refuse, and sometimes for peak loads. An auxiliary burner can provide continuity of steam supply during periods of refuse feed equipment failure or other up-stream problems. The standby package boiler is used when the thermal processing facility is totally inoperable. An increased number of parallel furnace lines may also be required to improve steam supply reliability.

The use of waste lubricating oils and other waste oils have been proposed as auxiliary fuels for steam generating incinerators.[6] However, such use requires precautions against hazardous contamination, such as flammable solvents; consideration of the possibility of steam tube fouling due to metallic impurities, which may include lead contents on the order of 1 percent in raw waste oils.[7]

Ideally, of course, the consumer has an alternative steam supply available, and therefore is not dependent on the solid waste generated steam. In this case, the steam will usually be less valuable to the consumer and lower prices will be obtained.

Air Conditioning. One recent project uses steam to heat downtown office buildings in the winter and to cool them in the summer.[8, 9] This idea of "District Heating and Cooling" is not new, having been practiced elsewhere, but the use of solid waste as the primary fuel is novel in the United States. The additional responsibility for supplying cooling in the form of chilled water further complicates the disposal task. Figure 30 depicts a complete system for accomplishing disposal, heating, and cooling.

In this plant, pumps are driven by non-condensing steam turbines, and water chillers are driven by condensing turbines using steam exhausted from the pump drives. The system is capable of producing 11.2 atm. absolute (150 psig) saturated steam for heating and 5 C (41 F) chilled water for cooling. A condenser is available to handle surplus steam; and standby package boilers are provided to supplement steam demands in order to increase overall plant reliability and operating flexibility during maintenance periods. Further detail is provided in Table 32.

Design and operation are complicated by peak daily demands and peak demands in winter for heating and in summer for chilling. Even for production of steam for both heat and chilling, the sum of the peak demand in the spring and the fall is less than individual demands for winter or summer. Since an incinerator normally must handle a specific daily tonnage of waste and will produce a fixed steam rate regardless of demand, it is evident that very careful analysis of supply and demand during the project planning phases is imperative.

SIMPLIFIED FLOW DIAGRAM
CENTRAL HEATING AND COOLING PLANT FUELED BY SOLID WASTE

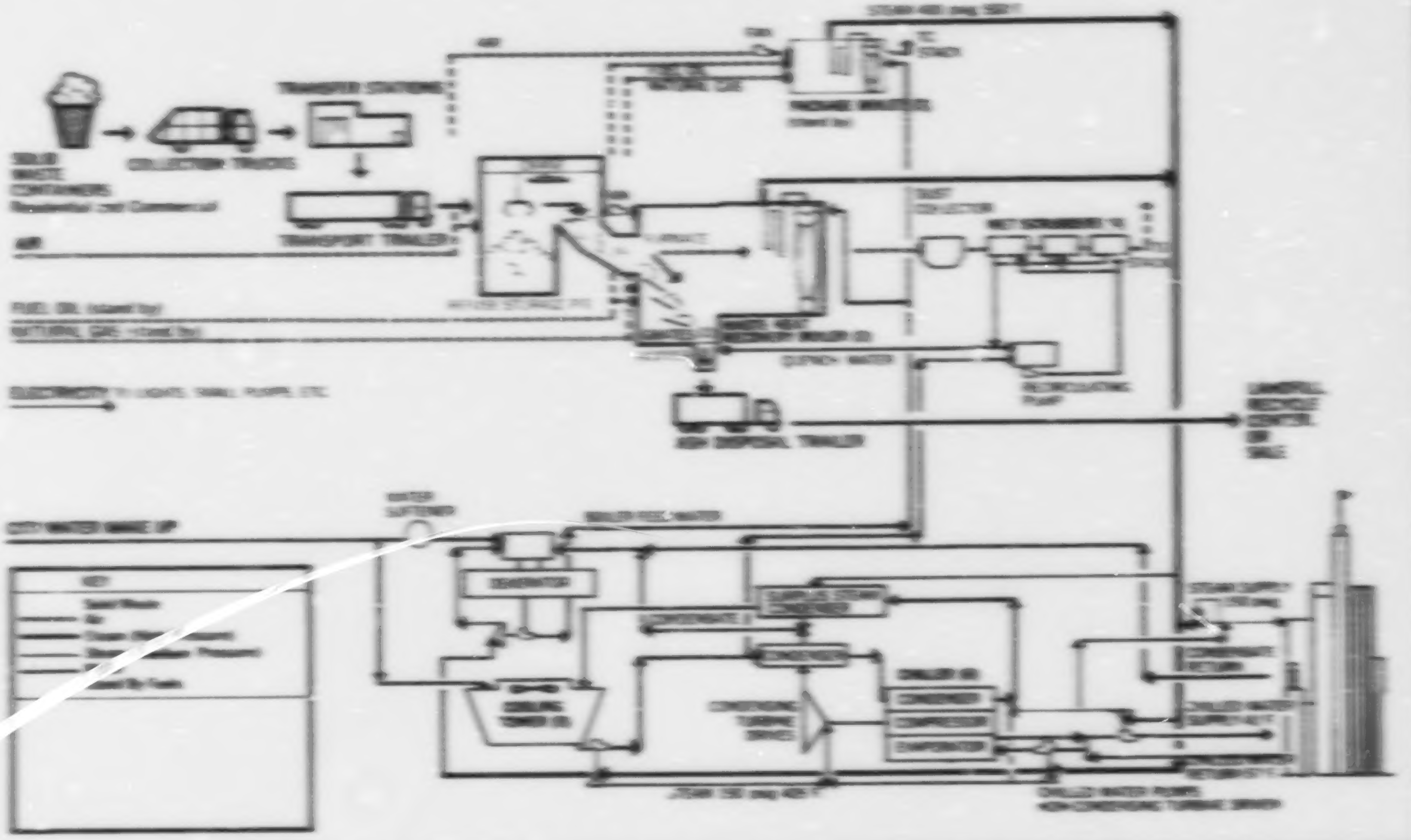

SOLID WASTE CONTAINERS Residential and Commercial
COLLECTION TRUCKS
TRANSFER STATIONS
TRANSPORT TRAILERS
AIR
FUEL OIL (stand by)
NATURAL GAS (stand by)
ELECTRICITY TO LIGHTS, FANS, PUMPS, ETC.
REFUSE STORAGE PIT
FURNACE
WASTE HEAT RECOVERY BOILER (S)
QUENCH WATER
ASH DISPOSAL TRAILER
DUST COLLECTOR
WET SCRUBBER (S)
RECIRCULATING PUMP
LANDFILL RECYCLE CENTER OR SALE
PACKAGE BOILER(S) (stand by)
STACK
CITY WATER MAKE UP
WATER SOFTENER
BOILER FEED WATER
DEAERATOR
COOLING TOWER (S)
SURPLUS STEAM CONDENSER
CONDENSATE
CONDENSER
CHILLER (S)
CONDENSER
COMPRESSOR
EVAPORATOR
CONDENSING TURBINE DRIVE
STEAM SUPPLY
CONDENSATE RETURN
CHILLED WATER SUPPLY
CHILLED WATER RETURN
CHILLED WATER PUMPS
KEY
Solid Waste
Air
Steam (High Pressure)
Steam (Medium Pressure)
Fired By Fuels

FIGURE 3[illegible]

Table 37

PERTINENT DATA FOR HEATING AND COOLING DISTRICT SUPPLIED BY SOLID WASTE GENERATED STEAM[8,9]

Total city refuse*	52.9 MT/hr.	(1400 ST/day)
Number of incinerators	2	
Capacity per incinerator	13.6 MT/hr.	(360 ST/day)
Number of buildings served	40	
Steam generation capacity (incinerators)	97.5 MT/hr.	(215,000 lbs./hr.)
Standby steam boiler capacity	56.7 MT/hr.	(125,000 lbs./hr.)
Steam pressure as generated	28.2 atm. abs.	(400 psig)
Steam temperature as generated	316 C	(600 F)
Steam pressure (saturated) supplied for heating and condensing turbines	11.2 atm. abs.	(150 psig)
Chilled water capacity	40.8×10^6 Kcal./hr.	(13,500 tons of refrigeration)
Chilled water supply temperature	5 C	(41 F)
Chilled water return temperature	14 C	(57 F)
Length of distribution pipeline	4.57 kilometers	(15,000 ft.)

* Parts of the distribution system and certain main plant components are designed for the projected ultimate plant capacity of 56.7 MT/hr (1500 ST/day) using five incinerators.

Other Energy Uses. Marketing steam and chilled water to municipally owned buildings, university complexes, and the like, for heating and cooling may be easiest institutionally, but industrial markets for process steam where demand is uniform, without exaggerated peaks and valleys, is much more satisfactory from the point of view of incinerator operation. Possible industrial consumers include power plants, oil refineries, chemical plants, and other plants utilizing low level energy (i.e., steam rather than direct firing of fuel, such as in glass or steelmaking furnaces).

Other process possibilities include municipal sewage sludge drying. Due to increasing environmental restrictions on ocean dumping and landfill operations, sewage sludge incineration is growing in importance. Use of hot flue gases or solid waste generated steam to predry the sludge results in economic and energy savings. Co-incineration of the dried sludge, or even the wet sludge, is also an interesting approach which has been used in the past to a limited extent.

Fresh water production from seawater or brackish water by distillation or other desalting processes requires energy which can be supplied from thermal processing facilities. This use, which can be considered in arid areas or other areas with special water problems, e.g., Southern California and Long Island, may be attractive because the pure water can be stored, allowing steady use of energy produced by the thermal processing facility.

Electricity can be produced from solid waste in four ways:

1. Generating steam to drive electrical generators.
2. Generating steam to sell to power companies.
3. Mixing prepared refuse with fossil fuel in power plant boilers.
4. High pressure, high temperature incineration using exhaust gases to drive an expansion turbine-generator.

While several European incinerators use steam produced to generate electricity, this approach is rare in the United States. The problems of inefficient generation from the relatively low pressure steam normally produced and the difficulties and cost in reliably producing high pressure, high temperature steam in solid waste incinerators appear to be formidable deterrent to this approach, though future improvements may be expected. Similarly, the sale of low pressure steam to electrical power companies is not usually attractive because steam pressures near 136 atmospheres (2000 psi) are preferred for efficient generation of electricity. Combined firing of prepared refuse with fossil fuel, which is attractive, will be covered in a later section of this Chapter. Direct production of electricity by incineration of prepared solid waste in a pressurized fluidized bed, and expansion of the hot gases through a turbine, though promising, has not yet reached commercialization.(3)

Energy Recovery Systems

Energy recovery may be accomplished in such diverse systems as pyrolysis processes, high pressure fluidized beds with gas turbines, and other methods which have not been demonstrated on a commercial scale. The systems described here generate steam by combustion of solid waste.

At least four general types of steam generation systems can be employed:

- Grate furnace with refractory walls and a waste heat boiler
- Grate furnace with water tube walls and a waste heat boiler
- Suspension fired steam boiler
- Combined firing of prepared refuse with fossil fuels

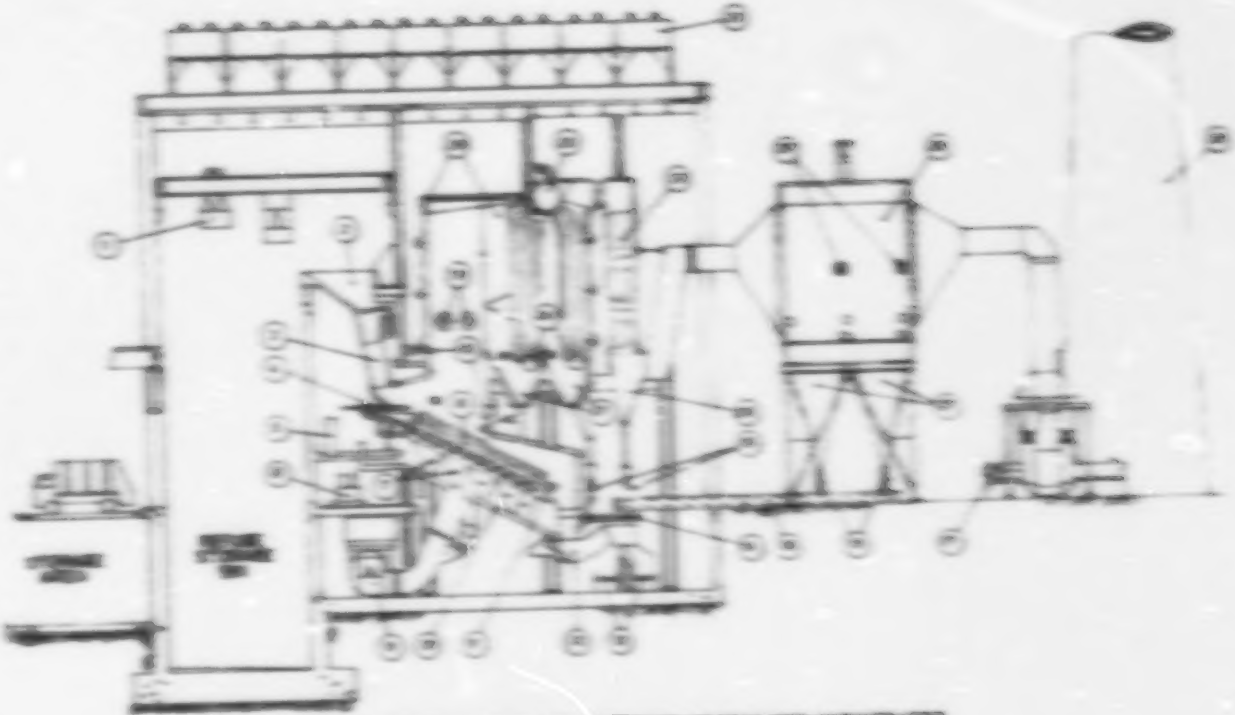
In the first two types, it is not necessary to shred or otherwise prepare the solid waste. In the latter two, preparation is required.

Refractory Incinerator with Waste Heat Boiler. This is a conventional incinerator with refractory walls followed by boiler tubes erected in the flue gas stream leaving the furnace. While this approach obviously produces energy credits, the full benefit of energy recovery is not achieved because considerable excess air must be used to control temperature in the combustion chamber. This excess air reduces the efficiency of energy recovery by carrying heat from the furnace system up the stack, and also requires larger downstream equipment, such as fans and air pollution control equipment, based on the high flue gas rate emitted. Careful design of boiler tubes is necessary to control temperature and to avoid slagging and corrosion.

Incinerator With Water Tube Walls. In the water tube wall incinerator firing unprepared waste, shown in Figure 31, heat is recovered directly from the combustion zone, eliminating the need for large quantities of excess air used for cooling in refractory incinerators. This is accomplished by the use of water tube walls in place of refractory, where water is circulated to remove energy, but reduces flue gas quantities significantly, reducing the size of downstream equipment. For example, the use of water tube walls may be expected to reduce flue gas quantity by 30 to 40 percent over a refractory furnace operating at the same temperature. Excess air requirements are usually on the order of 40 to 80 percent as compared to 100 to 200 percent often encountered in refractory furnaces.

Due to advantages of energy recovery and flue gas volume reduction, the newest steam generating incinerators have been of the water wall type. Tables 33 to 36 provide actual operating data for such an incinerator.

Suspension Fired Steam Boiler. The suspension fired steam boiler, shown in Figure 32, is based on the design of pulverized coal boilers commonly used throughout the world for electric power production and industrial boilers. Suspension firing has been used for other waste materials such as bark and bagasse,[13] but only recently has shredded waste been burned in suspension boilers.[14, 15, 16] In another, the prepared waste is burned with coal,[14] as described in the next section. A third suspension fired boiler is operated within an industrial plant.



CROSS SECTIONAL VIEW OF CHICAGO NORTHWEST INCINERATOR

LEGEND

(1)	Crane
(2)	Refuse Hopper
(3)	Refuse Chute
(4)	Refuse Feed
(5)	Stoker Control Panel
(6)	Reverse Reciprocating Stoker
(7)	Undergrate Air Plenum Chambers
(8)	Hydraulic Pump
(9)	Forced Draft Fan
(10)	Automatic Siftings
(11)	Clinker Roll
(12)	Residue Discharger
(13)	Residue Conveyor
(14)	Fly-Ash Conditioning Screw
(15)	Rotary Valves for Fly-Ash Discharge
(16)	Fly-Ash Flight Conveyor
(17)	Induced Draft Fan
(18)	Overfire Air Nozzles
(19)	Auxiliary Burners [illegible]
(20)	Radiant Waterwalls (Welded Panel Constr.)
(21)	Boiler Fly-Ash Hoppers
(22)	Steam Drum
(23)	Steam Condensers
(24)	Bottom Boiler Drum
(25)	Economizer
(26)	Economizer Fly-Ash Hopper
(27)	Fly-Ash Hoppers for Electrostatic Precipitators
(28)	Electrostatic Precipitator
(29)	Hoppers for Fly-Ash Collector Plates
(30)	Chimney

FIGURE 31. CHICAGO NORTHWEST STEAM GENERATING INCINERATOR[11]

Table 33

QUANTITIES AND FLUE GAS ANALYSIS FOR STEAM GENERATING INCINERATOR(1)

Heating value of refuse	2422 Cal/g	(4360 BTU/lb)
Incinerator capacity	15.2 MT/hr	(401 ST/day)
Refuse firing rate	15,166 kg/hr	(33,436 lb/hr)
Heat input	36.7x10^6 kcal/hr	(145,772,000 BTU/hr)
Gas exit temperature	211 C	(411 F)
Ambient air temperature	22.8 C	(73 F)
Gas Composition, Vol. %		
CO_2	10.49%	
O_2	9.02%	
CO	0.0 %	
N_2	80.49%	
Excess air	71.7 %	

Table 36

BOILER LOSSES AND EFFICIENCY FOR STEAM GENERATING INCINERATOR(1)

Heating value of refuse	2422 Cal/g (4360 BTU/lb)
Heat Losses	
Dry flue gas	11.40%
Moisture in fuel	4.01
Moisture in air	1.22
Moisture from burning hydrogen (H_2)	8.83
Combustible in residue	2.83
Moisture in residue	0.30
Moisture flashed from quench	0.32
Radiation loss	0.41
Unaccounted for losses	1.50
Total losses	30.82%
Efficiency	69.18%

Table 35

AIR AND GAS QUANTITIES FOR STEAM GENERATING INCINERATOR[1]

Heating Value of refuse	2422 Cal/g	(4360 BTU/lb)
Refuse firing rate	15,166 kg/hr	(33,434 lb /hr)
Dry gas per weight of refuse	6.14 kg/kg	(6.14 lb /lb)
Total moisture per weight of refuse	0.516 kg/kg	(0.516 lb /lb)
Weight of gas per weight of refuse	6.656 kg/kg	(6.656 lb /lb)
Gas temperature	211 C	(411 C)
Density of gas	0.734 kg/CM	(0.0458 lb/CF)
Density of water vapor	0.457 kg/CM	(0.0285 lb/CF)
Total weight of dry gas	93,117 kg/hr	(205,285 lb/hr)
Total weight of water vapor	7825 kg/hr	(17,252 lb/hr)
Total weight of products of combustion	100,942 kg/hr	(222,537 lb/hr)
Volume of Dry gas at 211 C(411 F)	2116 CM/min	(74,703 CF/min)
Volume of water vapor at 211 C (411 F)	282 CM/min	(9,950 CF/min)
Volume of products of combustion at 211 C (411 F)	2293 CM/min	(80,980 CF/min)
Available I.D. fan capacity at 260 C (500 F)	4030 CM/min	(142,300 CF/min)
Weight of air for combustion	85,102 kg/hr	(187,615 lb/hr)
Air volume at 21.1 C (70 F)	1182 CM/min	(41,750 CF/min)
Available FD fan capacity at 21.1 C (70 F)	2379 CM/min	(84,000 CF/min)

Table 36

OVERALL ENERGY RECOVERY PERFORMANCE OF STEAM GENERATING INCINERATOR[11]

Heating value of refuse	2422 Cal/g (4360 BTU/lb)
Steam generation per weight of refuse	2.98 kg/kg
Overall efficiency of incinerator and boiler	69.18%
Heat loss due to combustibles in residue	2.83%
Stack gas temperature	211 C (411 F)

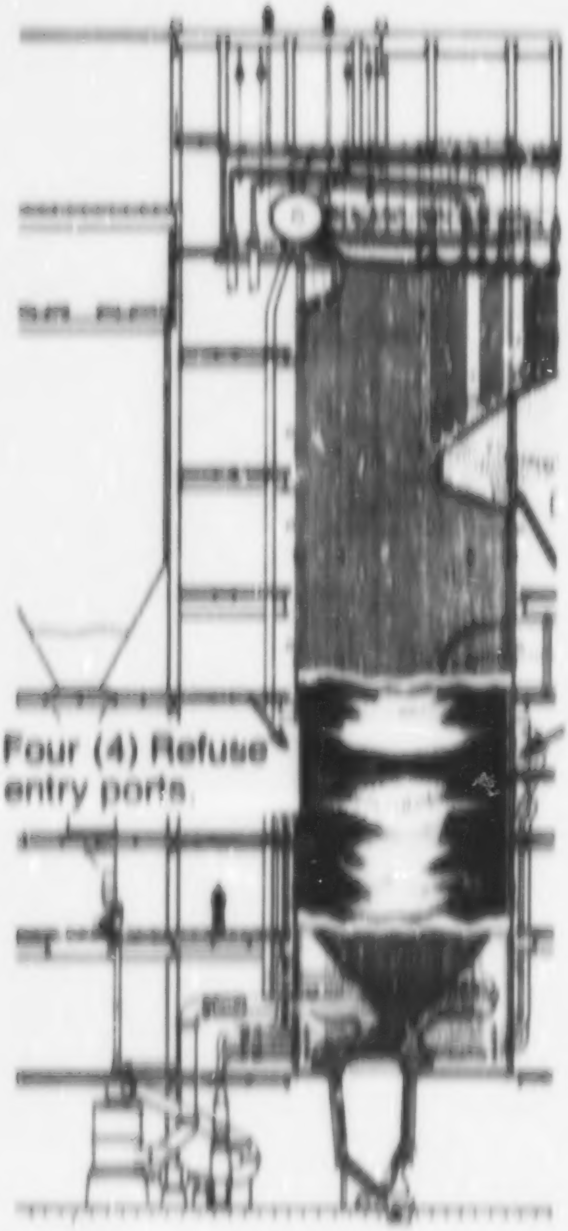

Four (4) Refuse entry ports.

FIGURE 32. SUSPENSION FIRED BOILER[17]

Prepared Refuse Combustion in Existing Boilers. A project which has created a great interest on a prototype scale (125 megawatt boiler) is the firing of prepared refuse in mixture with pulverized coal in an existing boiler. A commercial scale facility is planned by the participants. The attractive features of this approach include:

1. The boiler units are already in place, obviating the need for new thermal processing facilities.

2. Air pollution from sulfur oxides is reduced because the prepared refuse is normally lower in sulfur than the coal it replaced. Overall particulate emissions may also be reduced, compared to separate incineration, because of the separation of inorganic materials from the combustibles, and efficient electrostatic precipitators on the boiler.

3. Fossil fuel consumption for power generation will be reduced.

4. Facilities and markets already exist for the electrical energy produced.

The technique is based on the premise that if solid waste is prepared so that its flow characteristics are similar to pulverized coal, and its ratio to coal fired is kept low enough, the coal boiler will not be significantly affected and the above advantages will accrue. Tests to date show that efficient generation of electricity from prepared refuse can be accomplished by this approach. A single 500 megawatt boiler operated at 75 percent use factor could help dispose of 340,000 ST of solid waste per year, saving on the order of 160,000 ST of coal per year.

From the results obtained, it appears that on the order of 10 to 20 percent of the heating value fired in a normal coal-fired boiler can be supplied by solid waste which has been shredded and processed to recover noncombustibles such as metals and glass. These processing steps are expensive, but partially paid for by the recovered materials.

Particulate emission tests for combined firing have been inconclusive. The data obtained suggest possible problems with electrostatic precipitator performance when burning the prepared refuse with low sulfur coal. Such problems are common when burning low sulfur coal alone, but are costly to resolve.

The combined fossil fuel/refuse combustion approach requires additional demonstration in various types of boilers over an extended period of time before it can become a fully acceptable outlet for municipal solid waste disposal. Close observation is required to insure that no unusual corrosion or other detrimental effects occur.

The possibilities of firing prepared refuse in oil fired boilers is now undergoing study. These present special problems of refuse feeding techniques, disposal of residue, and particulate emission control, since adequate solids handling facilities and electrostatic precipitators are available on only a few boilers, those that have been converted from coal to oil firing.

Refuse-To-Energy Projects. A recent U.S. Environmental Protection report provides a recent list of municipalities committed to or having expressed an interest in resource recovery systems, most of which involve energy recovery.[17]

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CHAPTER XI

PYROLYSIS

Pyrolysis or "destructive distillation" is a process in which organic material is decomposed at elevated temperature in either an oxygen-free or low-oxygen atmosphere. Unlike incineration, which is inherently a highly exothermic combustion reaction with air, pyrolysis requires the application of heat, either indirectly, or by partial oxidation or other reactions occurring in the pyrolysis reactor. Again unlike incineration, which produces primarily carbon dioxide and water, the products of pyrolysis are normally a complex mixture of primarily combustible gases, liquids, and solid residues. Thus, pyrolysis produces products which are potentially useful as fuels and chemical raw materials.

Several pyrolysis processes have been developed for municipal solid wastes. One full-scale plant is in its early phases of operation in the City of Baltimore, and one is under construction in the County of San Diego. If operations are successful, pyrolysis will be available in the near future as an alternative to incineration and other methods of solid waste disposal.

Chemistry of Pyrolysis

The organic portion of municipal solid waste is primarily composed of the elements carbon, hydrogen, and oxygen, with minor quantities of nitrogen, sulfur and others. Since the ratios of the major elements approximate those in cellulose, municipal solid waste is sometimes represented chemically as $(C_6H_{10}O_5)_n$, where "n" represents a variable number of the basic chemical units. Indeed, cellulose is a major constituent of solid waste; for example, paper is primarily cellulose, wood contains about 50 to 60 percent cellulose, and cotton greater than 90 percent. For the purposes of this discussion, the chain or polymeric nature of cellulose will be ignored, using the chemical representation $C_6H_{10}O_5$.

Simple Pyrolysis. A simple pyrolysis reaction may be represented by:

$C_6H_{10}O_5 \longrightarrow$ Fuel gas (including some CO_2 + H_2O)

+ Pyrolytic Oil + other condensibles (oxygenated organics in water)
+ carbonaceous solid residue

The relative quantities of gaseous, liquid, and solid products and their compositions depend upon the composition of the waste and the conditions of pyrolysis. For example, higher pyrolysis temperature increases gaseous yields. Pyrolysis temperature for processes producing high yields of pyrolytic oil would be about 500 C (932 F), while processes producing primarily gaseous fuels will most likely attain 700 to 100 C (1292 to 1832 F). Solid residues are produced in either case.

Other Pyrolysis Reactions. Product yields can also be shifted by the applicator of catalysts, high pressure, by the use of oxidizing reactants such as air, oxygen, or water, or by the use of reducing reactants such as hydrogen or carbon monoxide. For example, the following types of reactions are possible:

$C_6H_{10}O_5 + 1/2\ O_2 \xrightarrow{\qquad} 6CO + 5H_2$ (partial oxidation)

$C_6H_{10}O_5 + H_2O \xrightarrow{\text{heat}} 6CO + 6H_2$ (reforming)

$C_6H_{10}O_5 + H_2 \xrightarrow{\text{pressure}}$ oil + H_2O (hydrogenation)

$C_6H_{10}O_5 + 12H_2 \xrightarrow{\text{pressure}} 6CH_4 + 5H_2O$ (hydrogasification)

$C_6H_{10}O_5 + CO + H_2O \xrightarrow{\text{pressure}}$ pyrolytic oil (hydro-oxynation)

Systems in which the partial oxidation and reforming reactions predominate would be expected to produce primarily fuel gas, with considerable oxygenated liquids under low temperature conditions.[1] Hydrogenation reactions may lead to oil (300 to 350 C, 200 to 300 atm)[2] or to methane (650 C, 80 to 200 atm)[3]. Hydro-oxynation, at 350 C and high pressure, yields pyrolytic oil. Carbonaceous residue is produced in all cases. Only simple pyrolysis and partial oxidation are practiced in the pyrolysis systems approaching commercialization.

The composition of fuel gases produced also depends upon pyrolysis conditions. Where air is introduced for partial oxidation, the fuel gas is diluted with N_2, limiting its use to industrial equipment especially designed for low volumetric heating value gases. Hydrogenation processes producing CH_4 result in higher heating value gases which may approach natural gas, depending mainly on the presence of unreacted H_2 which has an acceptable but lower volumetric heating value than CH_4. Gases containing CO/H_2 mixtures can be converted to natural gas substitutes.

Pyrolysis Product Compositions. A simple laboratory pyrolysis of dried shredded municipal wastes, with most of the inorganics removed, at about 500 C and atmospheric pressure resulted in the products in Table 37.[4]

The advantage for removal of inorganics from solid waste before pyrolysis can be inferred from the product compositions presented in Table 37. For example, even with prior removal of inorganics, the char produced contained a very high ash content, making this product only marginally useful. If inorganics, such as metals and glass, are not removed prior to pyrolysis, the higher ash content would most likely relegate the char to the status of a waste product. Therefore, resource recovery prior to pyrolysis is doubly advantageous.

Drying of wastes prior to pyrolysis is also advantageous. Condensation of water formed during pyrolysis produced the water fraction indicated in Table 37. If the waste had not been dried, this fraction would be even larger,

Table 37

SIMPLE PYROLYSIS

Fraction	Char	Pyrolytic Oil
Yield, weight %	20	40
Composition, weight %		
Carbon	48.8	57.5
Hydrogen	3.9	7.6
Nitrogen	1.1	0.9
Sulfur	0.3	0.1
Ash	31.8	0.2
Chlorine	0.2	0.3
Oxygen (by diff.)	13.9	33.4
	100.0	100.0
Heating Value, cal /g (BTU/lb)	6000 (9000)	5830 (10,500)

Fraction	Gas	Water
Yield, weight %	27	13
Composition	Volume %	Contains
	0.1 Water 42.0 Carbon Monoxide 27.0 Carbon Dioxide 10.5 Hydrogen 0.1 Methyl Chloride 5.9 Methane 4.5 Ethane 8.9 C_3 to C_7 hydrocarbons	Acetaldehyde Acetone Formic Acid Furfural Methanol Methyl Furfural Phenol Etc.
	99.0	
Gross Heating Value, Kcal /NCM (BTU/SCF)	5172 (580)	

diluting the soluble organics produced during pyrolysis and making more difficult their recovery or disposal. Feed moisture also adds to the amount of heat which must be added to the pyrolysis reactor.

As indicated earlier, higher pyrolysis temperature increases the amount of gaseous product. For example, for the combustible portion of a solid waste containing 19.77 percent free moisture, yields measured in the laboratory are shown in Table 38.[6] Gas composition also varies with pyrolysis temperature, with Table 39 showing hydrogen content increasing as temperature increases.[6] On the other hand, liquid composition does not change drastically with temperature, as shown in Table 40. An additional thirty three organic compounds were identified, but all were present in concentrations of less than about 0.3 percent.

As could be expected, char analyses in Table 41 show decreased volatile matter as pyrolysis temperature increases.[6]

Pyrolysis Processes

Early work in solid waste pyrolysis was naturally analogous to wood and coal pyrolysis or "destructive distillation." These have usually been batch retort or furnace processes with heat applied externally. However, recent developments in solid waste pyrolysis are in the direction of continuous modern engineering technology.

Many pyrolysis process developments have been undertaken in recent years.[7] Those believed to be under active development and to have reached the pilot plant stage on municipal solid waste are summarized in Table 42.

Only the Monsanto, Occidental, Union Carbide, and Carborundum processes are considered sufficiently advanced for further discussion here.

Monsanto Envirochem LANDGARD Process. The Envirochem LANDGARD System encompasses all operations for receiving, handling, shredding and pyrolyzing waste; for quenching and separating the residue; for generating steam from waste heat, and for purifying the off-gases. In the basic pyrolysis process, shredded waste is heated in an oxygen deficient atmosphere to a temperature high enough to pyrolyze organic matter into gaseous products and a residue consisting of ash, carbon, glass and metal. A flow chart and process description for the LANDGARD plant follow. (Figure 33).

Waste will be received from trucks and transfer trailers at the plant six days per week and metered from two live-bottom hoppers into their respective shredder lines. After shredding, waste is conveyed to a shredded waste storage system, from which it is continuously fed into the kiln.

Pyrolysis of shredded waste occurs in a refractory lined horizontal rotary kiln. Shredded waste feed and direct-fire fuel (oil) enter opposite ends of the kiln. Countercurrent flow of gases and solids exposes the feed to progressively higher temperatures as it passes through the kiln so that first drying and then pyrolysis occurs. The finished residue is exposed to the highest temperature, 982 C (1800 F), just before it is discharged from the kiln. The

Table 38

THE EFFECT OF TEMPERATURE ON PYROLYSIS YIELDS

Pyrolysis Temperature, °C	482	649	816	927
(°F)	(900)	(1200)	(1500)	(1700)
Product Yields, weight %				
Gases	12.33	18.64	23.69	24.96
Volatile Condensibles*	43.37	49.20	47.99	46.96
Other Condensibles	17.71	9.98	11.68	11.74
Char	24.71	21.80	17.24	17.07
	98.12	99.62	100.60	100.73

*Portion of condensibles which evaporate at 103 C, including water.

Table 39

THE EFFECT OF PYROLYSIS TEMPERATURE ON GAS COMPOSITION

Temperature, °C	482	649	816	927
(°F)	(900)	(1200)	(1500)	(1700)
Gas Composition, Volume %				
Carbon Monoxide	33.50	30.49	34.12	35.25
Carbon Dioxide	44.77	31.70	20.59	18.31
Hydrogen	5.56	16.66	28.55	32.48
Methane	12.43	15.91	13.73	10.45
Ethane	3.03	3.06	0.77	1.07
Ethylene	0.45	2.18	2.24	2.43
	99.74	100.00	100.00	99.99
Heating Value,* Cal /NCM	2930	3780	3680	3610
(BTU/SCF)	(312)	(403)	(392)	(386)

*Gross heating value by calculation.

Table 40

THE EFFECT OF PYROLYSIS TEMPERATURE ON ORGANIC PRODUCT COMPOSITION

Pyrolysis Temperature, °C	649	816
(°F)	(1200)	(1500)
Weight % of Condensible Organics		
Acetaldehyde	13.0	10.5
Acetone	18.0	16.5
Methylethylketone	4.3	4.9
Methanol	20.6	23.5
Chloroform	1.0	2.1
Toluene	1.3	3.2
Formic Acid	14.4	11.2
Furfural	7.2	8.0
Acetic Acid	1.3	2.1
Methylfurfural	6.9	6.7
Naphthalene	1.6	1.8
Methylnaphthalene	1.3	1.4
Phenol	6.5	5.6
Cresol	2.6	2.5
	100.0	100.0

Table 41

THE EFFECT OF PYROLYSIS OF TEMPERATURE ON CHAR COMPOSITION

Pyrolysis Temperature, °C	482	649	816	927
(°F)	900	1200	1500	1700
Char Composition, weight %				
Volatile Matter	21.81	15.05	8.13	8.20
Fixed Carbon	70.48	70.67	79.05	77.23
Ash	7.71	14.28	12.82	14.57
	100.00	100.00	100.00	100.00
Gross Heating Value, Cal/g	6730	6840	6400	6330
(BTU/lb)	(12,120)	(12,280)	(11,540)	(11,400)

Table 42

MUNICIPAL SOLID WASTE PYROLYSIS PROCESSES

Developer	Products	Pilot Plant Scale	First Commercial Plant
Monsanto Envirochem Systems, Inc., St. Louis, Mo.	Fuel Gas or Steam, Ferrous Metal, Wet Char, Glass Aggregate	35 ton/day	1000 ton/day; still in shakedown as of end of 1975; EPA support[a]
Occidental Research Corp. (formerly Garrett), La Verne, Calif.	Pyrolytic Oil, Char, Glass, Ferrous Metal, Non-Ferrous Metal, Organics in Condensate	4 ton/day	200 ton/day; startup scheduled for late 1976; EPA support[a]
Union Carbide Corp., New York, N.Y.	Fuel Gas, Slag	200 ton/day	Pilot plant still in operation in late 1975
Carborundum Environmental Systems, Inc., Niagara Falls, N.Y.	Steam (or Fuel Gas), Slag	75 ton/day	200 ton/day commercial plant under construction in Europe (Andco, Inc.)
Battelle Pacific Northwest Laboratories, Richland, Wash.	Steam (or Fuel Gas)	2 ton/day; 150 ton/day demonstration plant under consideration	-
Pyrolytic Systems, Inc., Riverside, Calif.	Fuel Gas or Electric Power	50 ton/day by late 1976	-
DEVCO Management, Inc., New York, N.Y.	Fuel Gas	50 ton/day	-

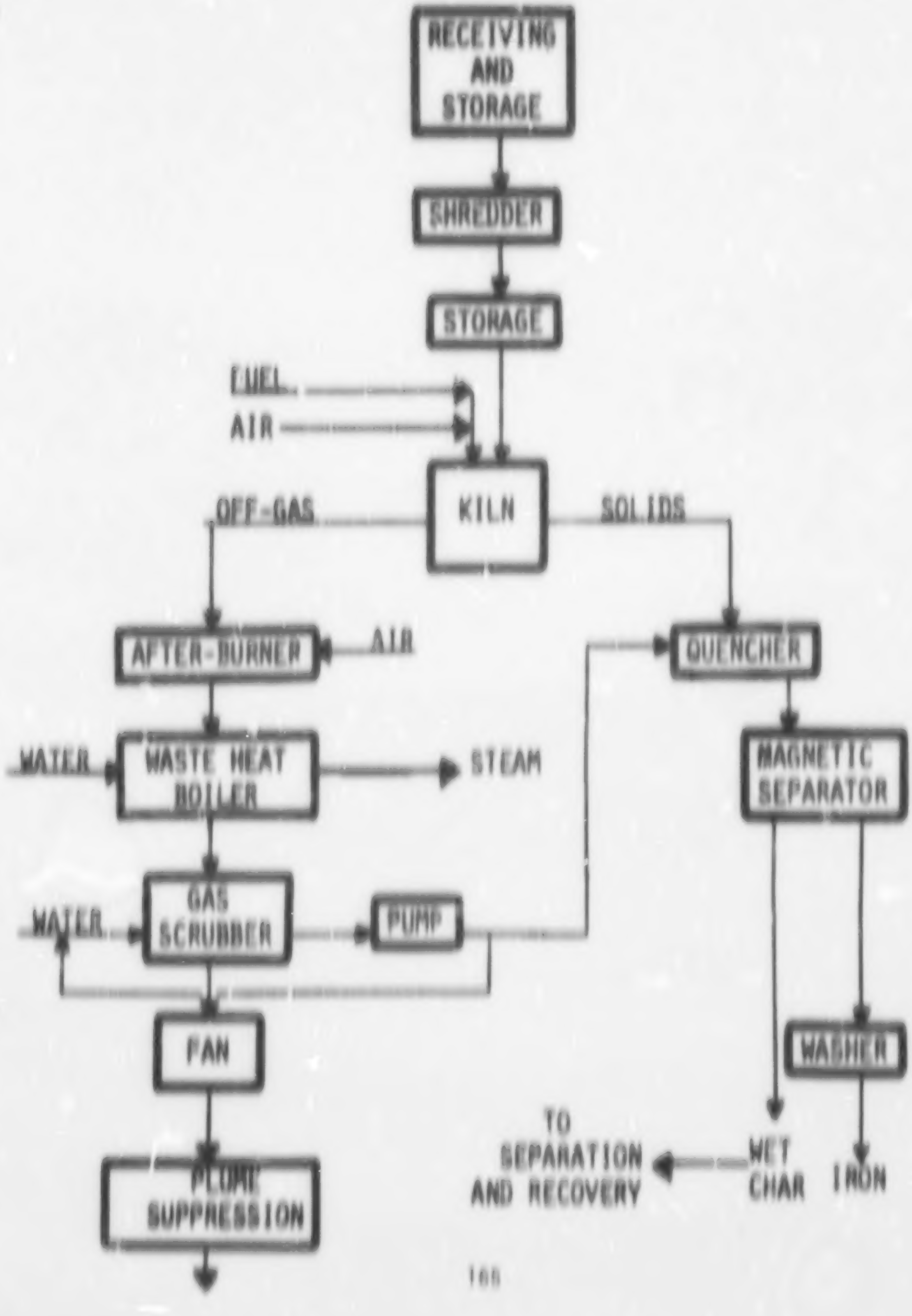
Table 42 (Continued)

MUNICIPAL SOLID WASTE PYROLYSIS PROCESSES

Developer	Products	Pilot Plant Scale	First Commercial Plant
Pollution Control, Ltd., Copenhagen, Denmark	Fuel Gas	5 ton/day	-
Urban Research & Development Corp., East Granby, Connecticut	Slag, Fuel Gas	120 ton/day	-

FIGURE 33.

LANDGARD PLANT FLOW SHEET


RECEIVING AND STORAGE
SHREDDER
STORAGE
FUEL
AIR
KILN
OFF-GAS
SOLIDS
AFTER-BURNER
AIR
QUENCHER
WATER
WASTE HEAT BOILER
STEAM
MAGNETIC SEPARATOR
WATER
GAS SCRUBBER
PUMP
FAN
WASHER
TO SEPARATION AND RECOVERY
WET CHAR
IRON
PLUME SUPPRESSION

kiln is specially designed (based on successful prototype operation) to uniformly expose solid particles to high temperatures. This maximizes the pyrolysis reaction. The kiln for the Baltimore demonstration plant is designed to handle 38 MT/hr throughput. It is 5.8 meters (19 ft) in diameter and 30.5 meters (100 ft) long, and rotates at approximately two revolutions per minute.

The hot residue is discharged from the kiln into a water-filled quench tank where a conveyor elevates it into a flotation separator. Light material floats off as a carbon char slurry, is thickened and filtered to remove the water, and conveyed to a storage pile prior to truck transport from the site. Heavy material is conveyed from the bottom of the flutation separator to a magnetic separator for removal of iron. Iron is deposited in a storage area or directly into a railcar or truck. The balance of the heavy material, now called glassy aggregate, passes through screening equipment and then is stored on-site. Plans call for eventual use of the glassy aggregate in "glasphalt" road construction.

Pyrolysis gases are drawn from the kiln into a refractory lined gas purifier where they are mixed with air and burned. The gas purifier prevents discharge of combustible gases to the atmosphere and subjects the gases to temperatures high enough for destruction of odors.

Hot combustion gases from the gas purifier pass through water tube boilers where heat is exchanged to produce about 2.4 tons of steam per ton of solid waste. Exit gases from the boilers are further cooled and cleaned of particulate matter as they pass through a water spray scrubbing tower.

Scrubbed gases then enter an induced draft fan which provides the motive force for moving the gases through the entire system. Gases exiting the induced draft fan are saturated with water. To suppress formation of a steam plume, the gases are passed through a dehumidifier in which they are cooled (by ambient air) as part of the water is removed and recycled. Cooled process gases are then combined with heat ambient air just prior to discharge from the dehumidifier.

Solids are removed from the scrubber by diverting part of the recirculated water to a thickener. Underflow from the thickener is transferred to the quench tank, while the clarified overflow stream is recycled to the scrubber. Normally all the water leaving this system will be carried out with the residue or evaporated from the scrubber.

Expected stack gas and residue analyses follow on Tables 43 and 44.

Occidental Process. A simplified flow diagram of the Occidental Research Corp. (formerly Garrett Research & Development Co.) recycling and pyrolysis process is shown in Figure 34. It incorporates the following operations:

1. Primary shredding of a raw refuse to minus two inches.
2. Air classification to remove most of the inorganics such as glass, metals, dirt, and stones from the organic feed to the pyrolysis reactor.

Table 43

STACK GAS ANALYSIS

	VOLUME %
o NITROGEN	78.7%
o CARBON DIOXIDE	13.8%
o WATER VAPOR	1.8%
o OXYGEN	5.7%
o HYDROCARBONS	<10 PPM
o SULFUR DIOXIDE	<150 PPM
o NITROGEN OXIDES	<65 PPM
o CHLORIDES	<25 PPM
o PARTICULATES	<0.02 GRAINS/SCF DRY GAS CORR. to 12% CO_2

Table 44

RESIDUE ANALYSIS

(WT.% DRY BASIS)

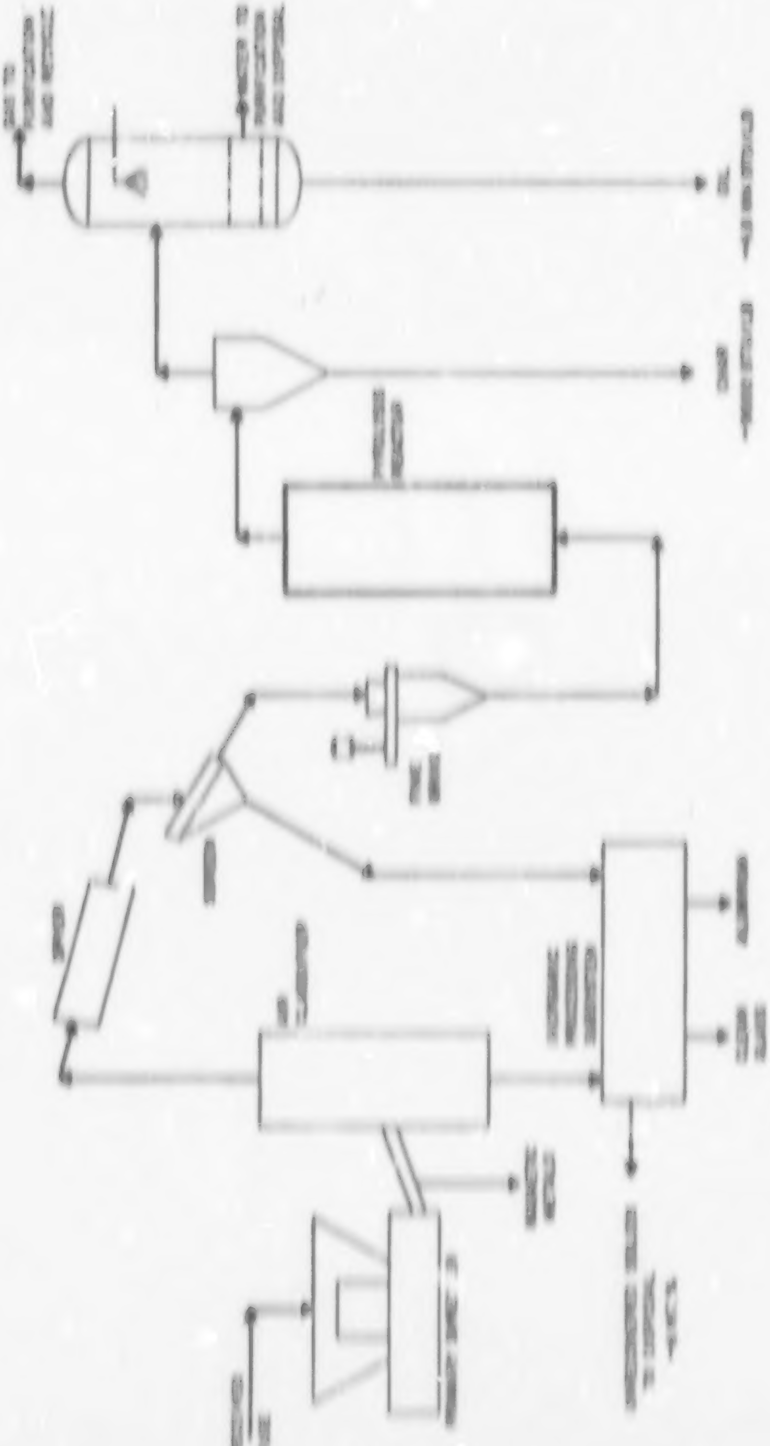
PROXIMATE ANALYSIS		ULTIMATE ANALYSIS	
VOLATILES	5.5	METAL (Fe)	21.9
FIXED CARBON	12.5	GLASS + ASH	60.1
INERTS	82.0		
		CARBON	14.5
		SULFUR	0.1
		HYDROGEN	0.5
		NITROGEN	0.2
		OXYGEN	2.7

HIGHER HEATING VALUE = 2500 BTU/LB

pH = 12.0

WATER SOLUBLE SOLIDS 2%

PUTRESCIBLES <0.1% (E/C ANAL. METHOD)



[illegible]

3. Drying of the air classifier overheads to about three percent moisture.

4. Screening of the dry material to reduce the inorganic content to less than four percent by weight.

5. Recovery of magnetic metals and glass cullett from the classifier underflow.

6. Secondary shredding of the dry organics to about minus 14 mesh.

7. Pyrolysis of the organics.

8. Collection of the pyrolytic products.

The first six of these unit operations may be conveniently grouped together as a feed preparation subsection, the primary function of which is to provide a dry, finely divided, and essentially inorganic-free feed to the pyrolysis reactor. An important secondary purpose is to allow the recovery of clean glass and magnetic metals.

The subsystem shown in Figure 36 is designed to recover over 70 percent of the glass in the refuse. A proprietary froth flotation technique is employed to obtain a sand-sized, mixed color product of better than 99.5 percent purity. Ferrous metals are recovered magnetically.

Screening the dry, air classified wastes successively at 0.635 centimeters (1/4 inch) and 14 mesh can reduce the inorganic content to about two weight percent. While about 12 to 14 percent of the organics pass through the screens, these are ultimately returned to the pyrolysis circuit by subsequent glass recovery operations.

The heart of the pyrolysis feed preparation lies in the secondary shredding operation. A finely divided organic feed to the pyrolysis reactor is desirable if high oil yields at atmospheric pressure are to be achieved.

The Occidental flash pyrolysis process involves the rapid heating in a transport reactor of finely shredded organic materials in the absence of air using recycled hot char to supply heat. This technique was developed to maximize liquid fuel yields. Typical yields were shown in Table 37. The gaseous fuel produced and a portion of the char are used on-site for process heat. Some No. 2 fuel oil, used with product oil to quench the process gas stream, is vaporized with uncondensed gas and also burned for process heat.

Water formed during pyrolysis and condensed from the product gas contains methyl chloride (from polyvinyl chloride pyrolysis) and other organic contaminants such as shown in Table 37. In the San Diego County demonstration project now under construction, these will be oxidized, using fuel gas for heat, in an afterburner (process heater). If markets were available for the energy in the char and fuel gas produced, there would be considerable incentive to develop biological or other treatment or recovery methods to dispose of the contaminated water.

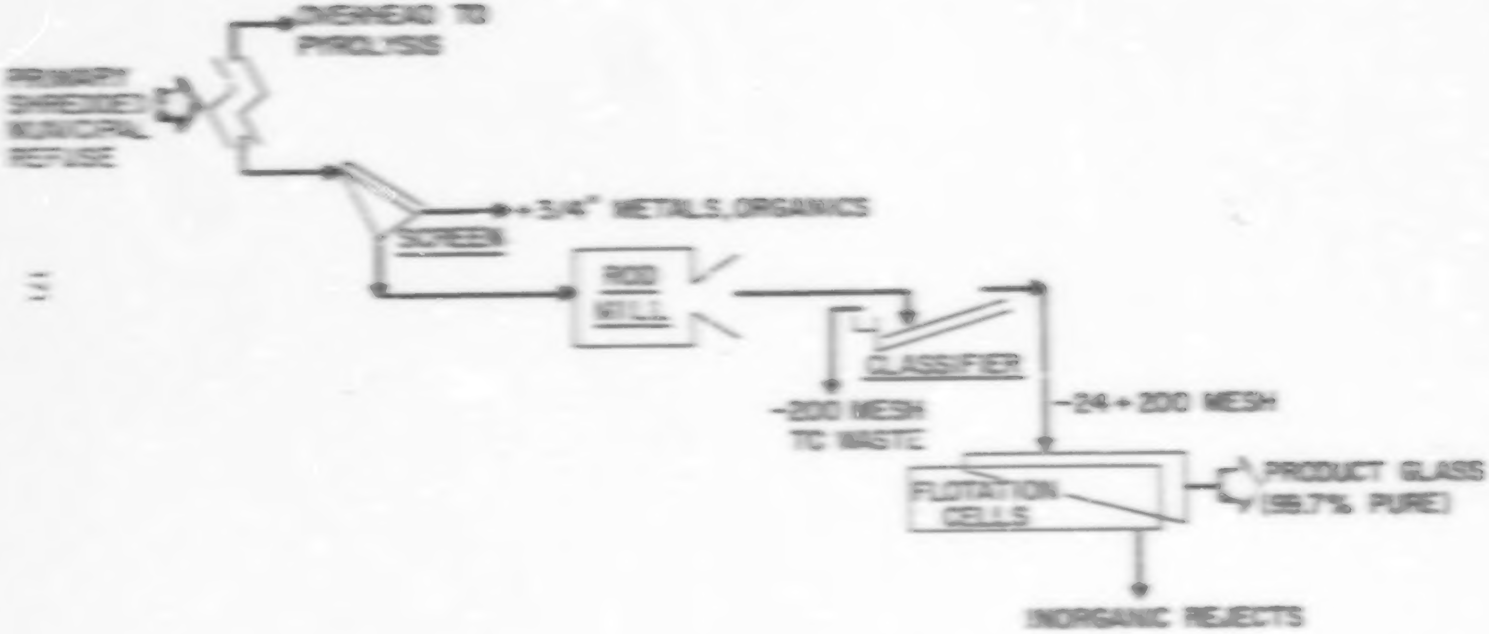

PRIMARY SHREDDED MUNICIPAL REFUSE
OVERHEAD TO PYROLYSIS
SCREEN
+3/4" METALS, ORGANICS
ROD MILL
CLASSIFIER
-200 MESH TO WASTE
-24+200 MESH
FLOTATION CELLS
PRODUCT GLASS (99.7% PURE)
INORGANIC REJECTS

FIGURE 35. GLASS RECOVERY IN OCCIDENTAL PYROLYSIS PROCESS

Air streams from the drier, air classifier, and pneumatic transport systems are used as combustion air and passed through the process heater combustion chamber. About 2500 cubic meters per metric ton (80,000 cubic feet per 2000 lbs.) of hot gas from the process heater (including one-third combustion products) are cooled by preheating various process gas streams, including combustion air for the char heater, and vented through a bag filter for particulate control.

The pyrolytic oil produced is the single most important product. A comparison between typical properties of No. 6 fuel oil and pyrolytic oil is shown in Table 45. Pilot-scale laboratory tests have indicated that the pyrolytic oil can be burned successfully in utility boilers.[9] The San Diego Gas and Electric Company will test and use the pyrolytic oil produced in the San Diego plant at one of its power generating stations. It is expected that at least 0.195 tons of pyrolytic oil will be produced per ton of solid waste (36 gal/ST).[9]

Union Carbide PUROX Process. PUROX is an oxygen based system to convert municipal refuse into a clean burning fuel gas and a compact, sterile residue. It combines the advantages of pyrolysis to produce useful and valuable by-products and high temperatures to melt and fuse the metal and glass. This is made possible by the use of oxygen in the conversion step.

The key element of the system is a vertical shaft furnace (Figure 36). As-received or preprocessed waste is fed into the top of the furnace, and oxygen is injected into the bottom. The oxygen reacts with char formed from the waste. This reaction generates the high temperature in the hearth needed to melt and fuse the metal and glass. This molten mixture drains continuously into a water quench tank where it forms a hard granular material.

The hot gases formed by reaction of the oxygen and char rise up through the descending solid waste and pyrolyze the waste as it cools. In the upper portion of the furnace, the gas is cooled further as it dries the incoming material. This results in the gases exhausting from the furnace at about 93 C (200 F). The exhaust gas contains considerable water vapor, some oil mist, and minor amounts of other undesirable constituents. These components are removed in a gas cleaning system.

The resultant gas is a clean burning fuel with about 2821 calories per NCM (300 BTU/SCF) gross heating value (Table 46). It is essentially free of sulfur compounds and nitrogen oxides. It can be effectively used as a supplementary fuel in an existing utility boiler or other fuel consuming operation. The combustion products of this fuel should easily meet air pollution codes.

The Union Carbide system is a net producer of energy. The clean burning fuel gas represents 83 percent of the fuel value of the original solid waste charged to the conversion system. A minor portion of this fuel gas is used to generate process steam, for building heat, and for the heat energy needed to maintain the auxiliary combustion chamber at operating temperatures. After deducting the aforementioned uses for the fuel gas, approximately 76 percent of the fuel energy in the municipal solid waste would be available in the remaining fuel gas for other purposes. An energy balance is shown in Table 47.

Table 45

TYPICAL PROPERTIES OF NO. 6 FUEL OIL AND PYROLYTIC OIL

	No. 6	Pyrolytic Oil
Carbon, wt. %	85.7	57.5
Hydrogen	10.5	7.6
Sulfur	0.7 - 3.5	0.1 - 0.3
Chlorine	-	0.3
Ash	0.5	0.2 - 0.4
Nitrogen	2.0	0.9
Oxygen	2.0	33.4
Gross Heat of Combustion, cal./g. (BTU/lb.)	10,100 (18,200)	5,800 (10,500)
Specific Gravity	0.98	1.30
Pour point F	65 - 85	90*
Flash Point F	150	133*
Viscosity SSU @ 190 F	340	1,150*
Pumping temperature F	115	160*
Atomization temperature F	220	240*

*Oil containing 14 wt. % moisture

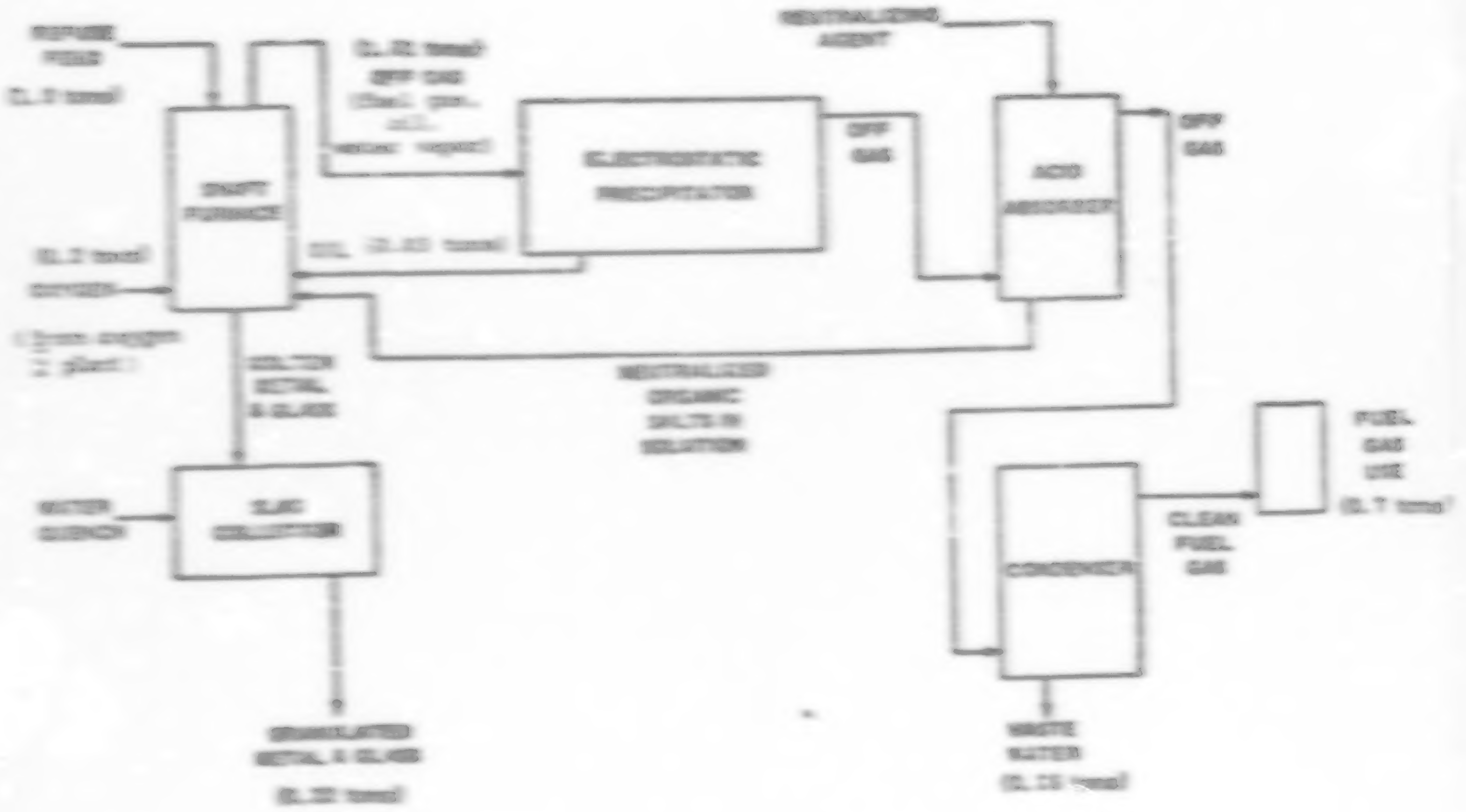

REFUSE FEED
(1.0 tons)
(0.[illegible] tons) OFF GAS ([illegible] gas, oil, water vapor)
SHAFT FURNACE
(0.2 tons) OXYGEN
(from oxygen plant)
OIL (0.[illegible] tons)
ELECTROSTATIC PRECIPITATOR
OFF GAS
NEUTRALIZING AGENT
ACID ABSORBER
OFF GAS
MOLTEN METAL & GLASS
NEUTRALIZED ORGANIC SALTS IN SOLUTION
WATER QUENCH
SLAG COLLECTOR
GRANULATED METAL & GLASS
(0.[illegible] tons)
CONDENSER
WASTE WATER
(0.[illegible] tons)
CLEAN FUEL GAS
FUEL GAS USE
(0.7 tons)

FIGURE 38. BLOCK DIAGRAM—OXYGEN REFUSE CONVERTER

Table 46
FUEL GAS COMPOSITION

Constituent	Volume %
CO	49
H_2	29
CO_2	15
CH_4	4
C_2H_2 +	1
N_2 + Argon	2
Totals	100

Table 47

USAGE OF AVAILABLE ENERGY

1000 ST/D OXYGEN REFUSE

CONVERTER FACILITY

	BTU/Hour	Percent
Available Energy in Refuse *	416,000,000	100
Energy Losses in Conversion Process †	70,000,000	17
Energy Available in Fuel Gas	346,000,000	83
Fuel Gas Uses		
Process Steam	16,000,000	4
Building Heating	10,000,000	2
Energy to Maintain Auxiliary Combustion Chamber at Operating Temperature	7,000,000	2
Net Energy Available in Fuel Gas	313,000,000	75
Electric Power Generation		30,000 KW ‡
Electric Power Used in Plant		5,000 KW
Electric Power Available for Export		25,000 KW

*Based on a refuse heating value of 5000 BTU/lb., this is calculated as (5000) (2000) (1000)/24.

†Includes latent heat of moisture in refuse, sensible heat of fuel gas, heat content of molten slag and metal, and heat leak.

‡Based on combustion of the net fuel gas in a gas utility boiler with an efficiency of 10,433 BTU/KWH (32.7% overall efficiency).

If the fuel gas is used as a supplementary fuel in an existing fossil fired steam boiler, the net energy production is shown in Table 47. For example, the fuel gas from a 1000 ST/day disposal facility could produce 30,000 KW of electric power. Electric power required in the refuse facility is approximately 5000 KW (including power required to separate oxygen from air), resulting in 25,000 KW available for use elsewhere.

The residue produced from the noncombustible portion of the refuse is sterile and compact. Because it has gone through the molten state, it is free of any biologically active material and has been fused to a minimum volume. There is no need to use sanitary landfill techniques for disposal, and it is suitable as a construction fill material. The volume of the residue is two to three percent of the volume of the incoming refuse, depending upon the amount of noncombustible material contained in the refuse. This compares with a residue volume of 5 to 15 percent for a conventional incinerator.

An important feature of the PUROX system is that a minimum amount of other materials are introduced and processed with the refuse. This is shown clearly by comparing PUROX with a conventional refractory incinerator. Because a conventional incinerator burns the refuse with an excess amount of air, about seven tons of air are introduced per ton of refuse combusted. This compares with one-fifth of a ton of oxygen introduced per ton of refuse for the PUROX system. This is a 35 fold difference. This difference in input is reflected by a 20 fold difference in volume of gas to be cleaned. This advantage is, of course, offset in part by the cost of separating oxygen from air, or for purchasing oxygen.

Carborundum Torrax System. The Torrax (or Andco-Torrax) System is designed to convert the combustibles in mixed municipal solid waste to a fuel gas by partial oxidation with air, while melting non-combustibles at temperatures up to 1650 C (3000 F). The waste is processed without sorting or pre-treatment.

The combustible gas produced is of a relatively low heating value, 1130 to 1400 Kcal/NCM (120 to 150 BTU/SCF). The fuel gas can be used in various ways as a source of energy, but, because of its low heating value, it will usually be advantageous to burn the gas and to recover the heat in a waste heat boiler onsite to produce steam for export, or for conversion to electrical power.

The Torrax System consists of the following major subsystems:

1. Gasifier for pyrolysis slagging

2. Secondary combustion chamber to complete oxidation of volatile materials from pyrolysis

3. Regenerative towers for primary combustion air preheating

4. Waste heat boiler to burn fuel gas and convert energy to steam

5. Gas cleaning system

A diagram of the system is provided in Figure 37.

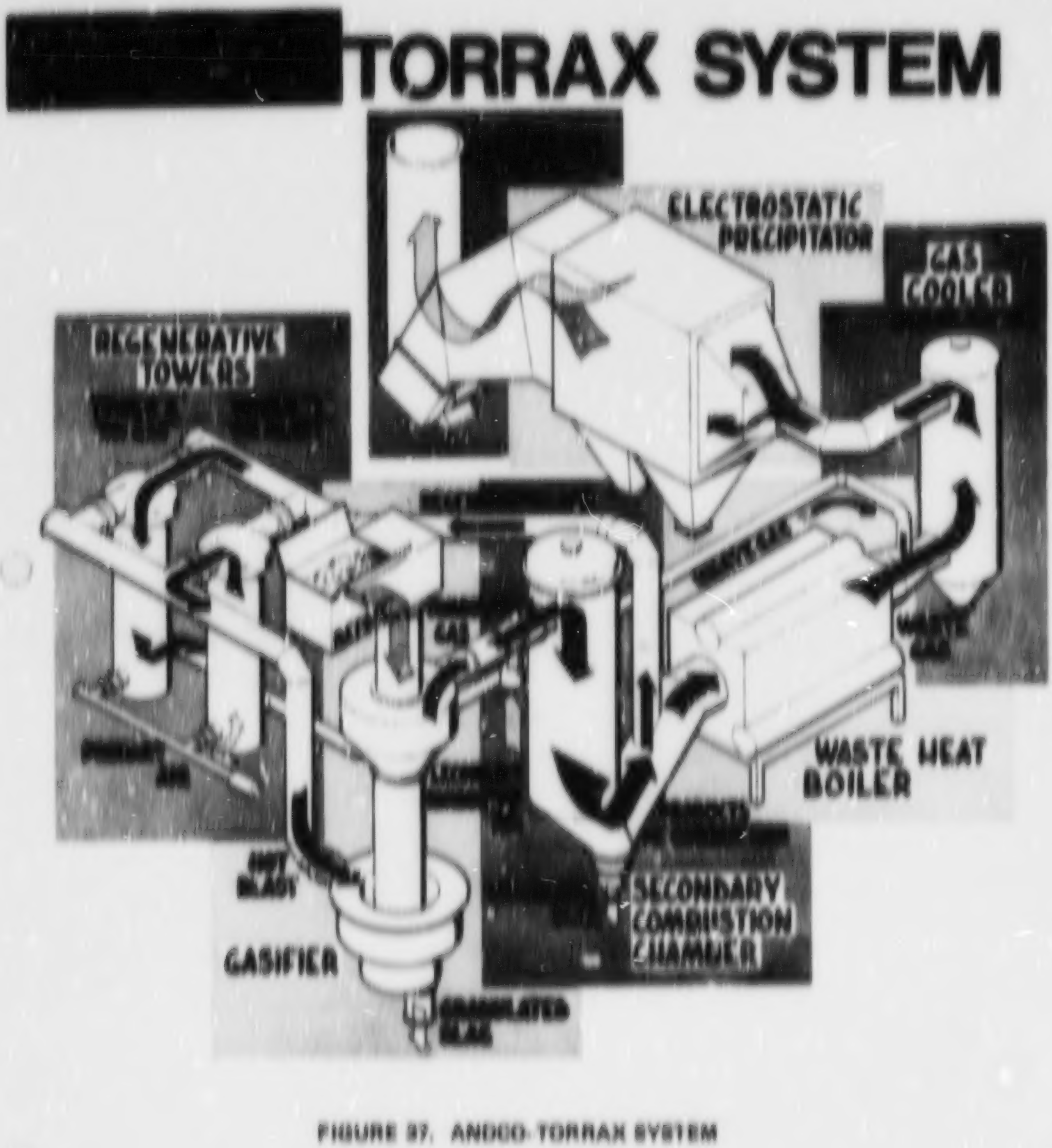

TORRAX SYSTEM
ELECTROSTATIC PRECIPITATOR
GAS COOLER
REGENERATIVE TOWERS
WASTE GAS
WASTE HEAT BOILER
SECONDARY COMBUSTION CHAMBER
GASIFIER
GRANULATED SLAG

FIGURE 37. ANDCO-TORRAX SYSTEM

Grapple bucket lifts are used to charge waste into the inlet hopper of the gasifier without sorting or pre-treatment, except that pieces of refuse larger than one meter in any dimension are sheared before charging. An automatic feeder moves the waste from the hopper into the shaft of the gasifier, as shown in Figure 30. The waste solids then descend by gravity through the drying, pyrolysis, the primary combustible zones of the gasifier. Primary combustion air from the regenerative towers at 1100 C (2000 F) is introduced with some auxiliary fuel at the tuyeres near the base of the gasifier, while the pyrolysis vapors are drawn out of the gasifier in the drying area. The molten slag tap into a water quench tank to produce a black, glassy aggregate free of carbon or putrescible material. The quantity and composition of the aggregate will vary with the waste fed, but an example is provided in Table 46. The size of a single gasifier is limited to about 11 MT/hr (300 ST/day).

The pyrolysis vapors from the gasifier at 450 to 550 C (800 to 1000 F) are thoroughly mixed with minimum excess air (10 to 15 percent) and burned at 1200 to 1260 C (2200 to 2300 F) in the secondary combustion chamber. The high temperature causes flyash and other inert carry-over materials to fuse and be slagged out of the stream. This slag, which is water-quenched, is approximately 10 percent of the total aggregate produced.

Two refractory-filled steel shells, called regenerative towers, are used to recover heat from about 15 percent of the hot combustion gas to heat the primary combustion air. These are automatically and alternately controlled to heat the air to 982 to 1149 C (1800 to 2100 F) and to cool that portion of the combustion gas used in this subsystem.

The major portion (85 percent) of the combustion gas from the secondary combustion chamber is cooled in the waste heat boiler to about 260 C (500 F), producing as much as three tons of steam per ton of municipal solid waste.

The waste gases from the regenerative towers and the waste heat boiler are combined, cooled to 300 C (550 F) by water spray or tempering air, and cleaned with a conventional air pollution control system, such as a scrubber or electrostatic precipitator. The normal gaseous emission will contain 81 percent N_2, 16 percent CO_2, and 3 percent O_2 by volume.

Sewage sludge, waste oil, unshredded tires, and polyvinylchloride have been burned with municipal waste in the Torrax pilot unit.

Summary

Each of the pyrolysis processes discussed will undergo sufficiently large-scale demonstrations, in the period 1976-1977, so that the successful processes can be considered as an alternative for municipal solid waste disposal. The obvious advantages of converting solid waste to a valuable energy resource merits a very close examination of this possibility.

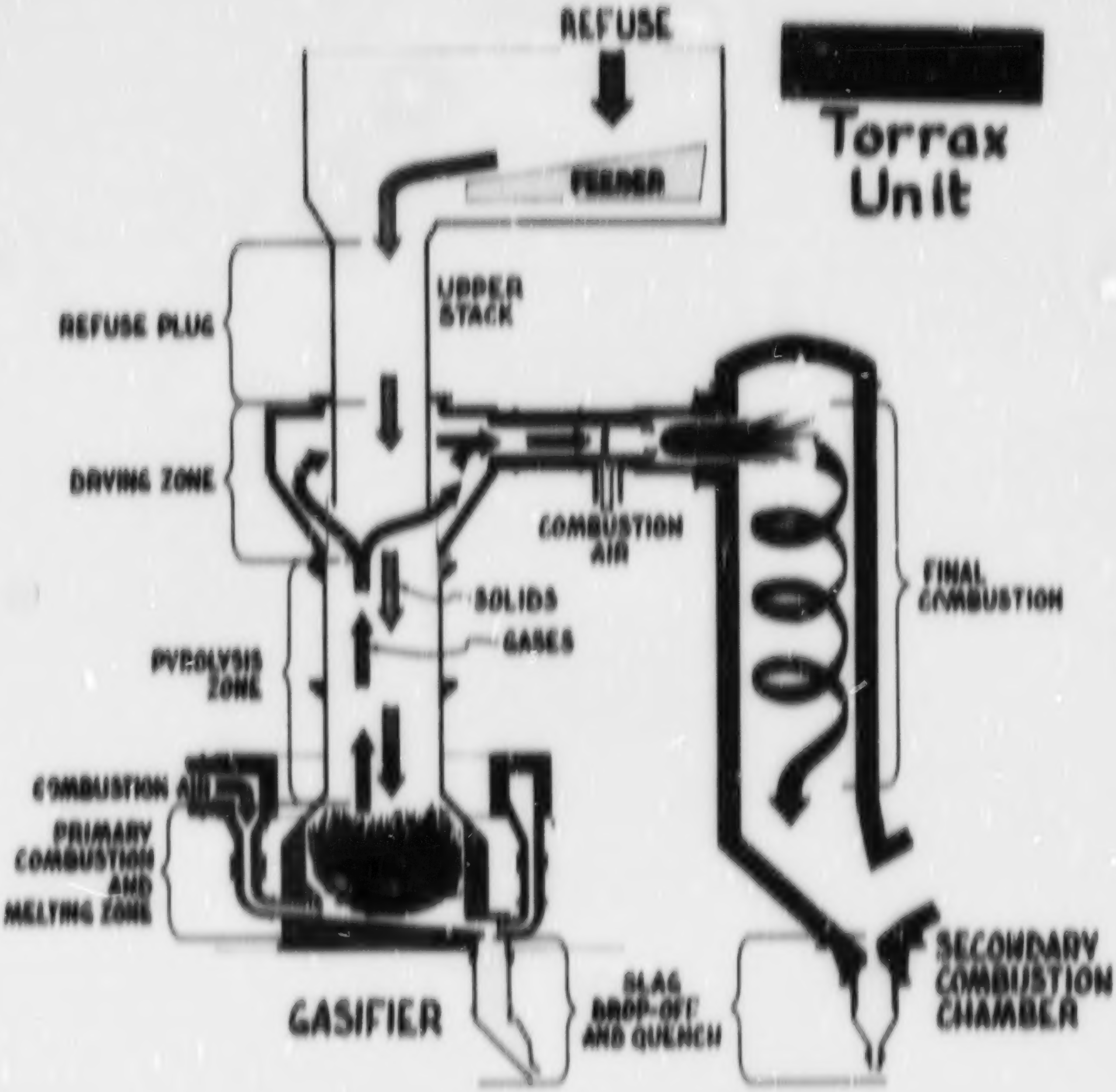

REFUSE
FEEDER
Torrax
Unit
UPPER STACK
REFUSE PLUG
DRYING ZONE
COMBUSTION AIR
SOLIDS
GASES
PYROLYSIS ZONE
FINAL COMBUSTION
COMBUSTION AIR
PRIMARY COMBUSTION AND MELTING ZONE
GASIFIER
SLAG DROP-OFF AND QUENCH
SECONDARY COMBUSTION CHAMBER

FIGURE 38. ANDCO-TORRAX UNIT

Table 48

TORRAX AGGREGATE

Constituent	Average % (by weight)	Range %
SiO_2	45	32.-58.
Al_2O_3	10	5.5-11.
TiO_2	0.8	0.40-1.3
Fe_2O_3	10	0.5-22.
FeO	15	11.-21.
MgO	2	1.8-3.3
CaO	8	4.8-12.1
MnO	0.6	0.2-1
Na_2O	6	4.-6.6
K_2O	0.7	0.35-1.1
Cr_2O_3	0.5	0.11-1.7
CuO	0.2	0.11-0.29
ZnO	0.1	0.02-0.26
Dry Bulk Density	1.40 g./cc	
True residue	2.80 g./cc	
Screen size	4% >3 1/2 mesh (5.66 mm) 2% <30 mesh (0.59 mm)	

Quantity,
% of municipal solid waste charge: 3-5 by volume; 15-20 by weight

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CHAPTER XII

INSTRUMENTATION AND CONTROLS

Modern thermal processing systems are becoming much more complex, incorporating energy recovery, resource recovery, air and water pollution control, or other features which require instrumentation to a degree greater than that previously required just for proper combustion control.

Instrumentation is needed to:

1. Control and monitor the basic incineration or pyrolysis process.
2. Control and monitor associated subsystems such as steam generation, power generation, and resource recovery.
3. Control and monitor environmental subsystems such as flyash collection, wastewater treatment, and visible plume control.
4. Protect equipment, for example, against corrosion, heat destruction, mechanical destruction, and operator abuse.
5. Collect data for calculating disposal costs and charges, making improvements, and designing additional facilities.

The degree of automatic versus manual control will depend not only on technical considerations, but on capital and operating budgets, and personnel policies regarding the experience and qualifications of plant operators. In some cases, television monitoring, computer control, and digital data acquisition systems may be justified.

Instruments measure, indicate, transmit and record important process conditions, including flow, temperature, pressure, weight, position, time, speed, voltage and composition. Controls change these conditions, either manually or automatically, in response to a signal from a measuring instrument.

Control systems, either manual or automatic, are necessary because, as in any process, many input factors are variable, but the end result must be the same. That is, for example, an incinerator should process refuse to a substantially reduced volume of inert residue containing no putrescible materials without harming the environment, the equipment, or personnel, regardless of the composition and wetness of the refuse, atmospheric conditions, time of year, equipment condition, or other vagaries.

Incinerator Process Instrumentation

Effective combustion in incinerator furnaces requires the use of manual and/or automatic controls. Combustion is controlled by residence time, furnace temperature, contact between combustibles and oxygen, and use of auxiliary fuel). Residence time, in turn, is controlled by grate speed, assuming adequate raw feed (limited by crane capacity). Furnace temperatures are controlled by the ratio of total air flow to refuse and by overfire and underfire air rates. The importance of excess air in determining furnace temperatures was discussed in Chapter IX. Contact is a function of furnace and grate design, but some control is possible by variations in underfire air and mechanical grate action. Most of these variables are interdependent and a change in one is likely to require a change in another.

Following is a discussion of the basic requirements for control of the major variables of an incinerator, as illustrated in Figure 39.

Underfire Air Control. This is the primary source of oxygen for solid waste combustion. Requirements are affected by the nature of the waste, including percent combustibles, density, moisture content, and determined only by measuring performance (e.g. visible appearance of burning bed, reduction of refuse volume, burnout). Insufficient underfire air will result in incomplete combustion; large excesses may increase flyash generation. Since continuous sensing and measurement of waste characteristics is impractical, the underfire air can be controlled at a present level by sensing the flow in a duct and adjusting flow by adjusting dampers or fan speed. A simple control schematic is shown in Figure 40.

Overfire Air Control. This is the secondary source of oxygen for combustion, especially for oxidizing refuse decomposition products contained in the gases, and the primary source of dilution air for cooling. Requirements are affected by the nature of the waste, but can be dynamically controlled by temperature sensing. Temperatures which are too low result in unburned gases and odors; furnaces or steam tubes can be damaged (by heat destruction and/or corrosion) if temperatures are too high. The overfire air can be controlled at a present level as with the underfire air, or it can be controlled by adjusting dampers or fan speed in response to temperature measurement. A simple temperature control schematic is shown in Figure 41. Overfire and underfire air ratio control is sometimes used.

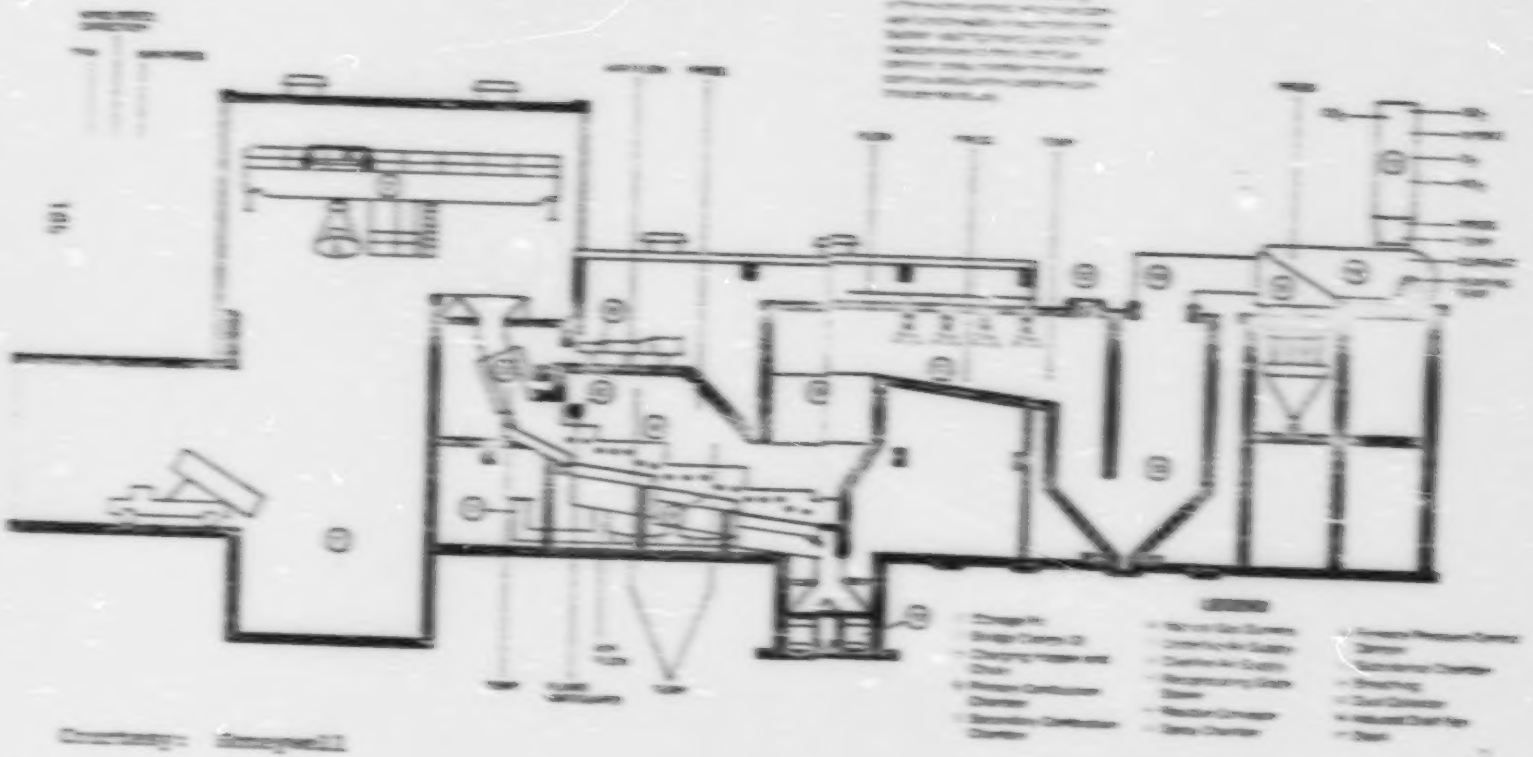
Draft Control. Draft refers to the pressure distribution required for maintenance of the proper flow in the desired direction. A prime requirement is to keep the furnace under a slight vacuum to prevent the escape of hot gases and odor. In a modern incinerator, draft is maintained by the use of an induced draft fan which compensates for variations in overfire and underfire air by drawing outside air into and through the furnace, often from the pit area for odor and dust control. Induced draft fan operation can be preset, or its speed can be controlled in response to a pressure measurement. A simple control schematic is shown in Figure 42.

Auxiliary Burner Controls. These are sometimes used as a source of additional heat to sustain combustion during startup, transient, and wet feed

Refuse Incineration

[illegible]

[illegible]



Courtesy: [illegible]

FIGURE [illegible]. INCINERATOR CONTROLS

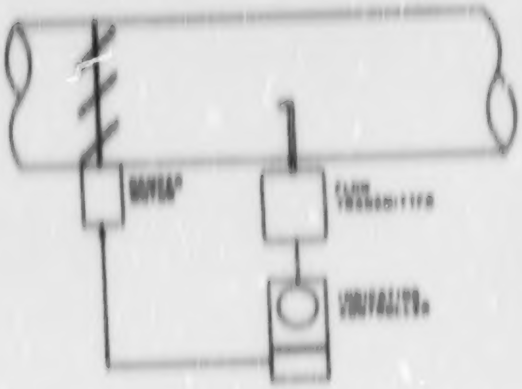


FIGURE 40. UNDERFIRE AIR FLOW CONTROL SYSTEMS

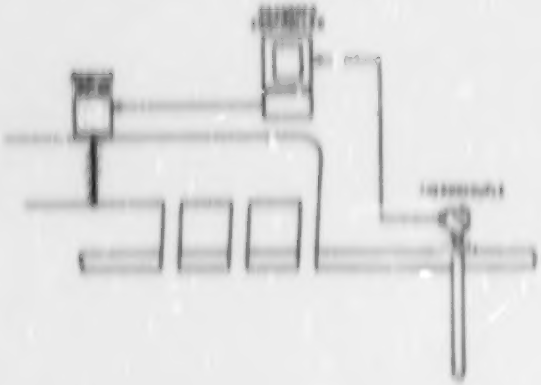


FIGURE 41. FURNACE TEMPERATURE CONTROL SYSTEM

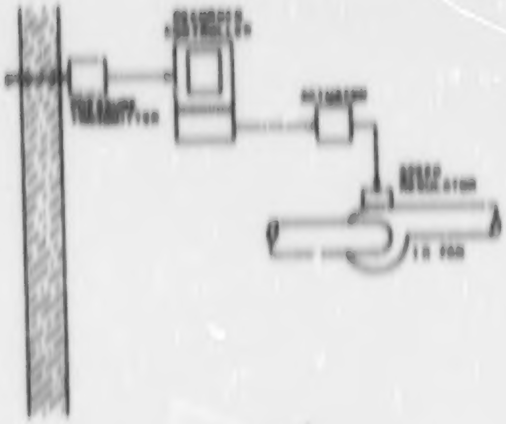


FIGURE 42. FURNACE PRESSURE CONTROL SYSTEM

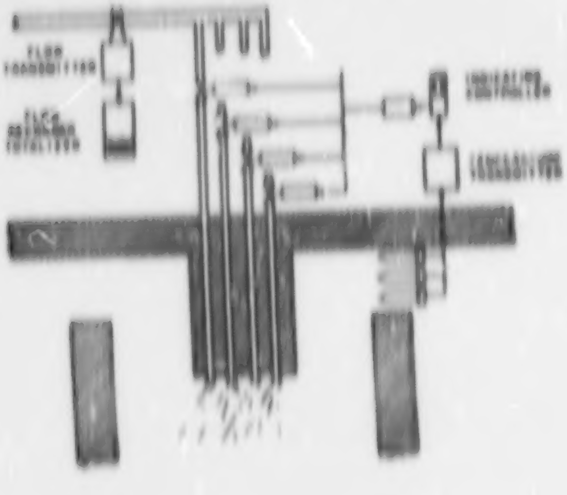


FIGURE 43. SPRAY CHAMBER TEMPERATURE CONTROL SYSTEM

periods. Generally on-off burners are sufficient, but standard burner train controls are required for safety, e.g. flameguard and purging systems. Burners are useful for systems generating steam to sustain output when sufficient solid waste is not available to meet peak steam demands, and when the heating value is low due to wetness, or for other reasons.

Grate Controls. The grates must provide solids movement, agitation, and passage for underfire air. Grate speed controls residence time, and it can also be used to control temperature. As many as four grate sections with separate speed controls have been used. Residence time requirements are affected by the nature of the waste, but, as previously noted, waste characteristics cannot be continuously measured. Therefore, sufficiency of residence time (and temperature and turbulence) is judged by visually observing combustion and periodically measuring burnout. Grate speed and, if possible, bed depth and turbulence are manually adjusted accordingly.

Feed Conveyors or Crane Control. These are required to bring the waste from a storage area to the combustion zone. Cranes are manually operated simply to keep feed hoppers full. Feed conveyors, where used, require speed control, obviously to coincide with grate speeds. Ram feeders are finding some favor, and hopper gates have been used to control solid feed rate from the hoppers to the grates.

Flue Gas Cooling Control. Cooling is practiced to reduce gas volume and to protect downstream equipment, e.g. induced draft fans, flyash collection equipment, and the stack from heat damage. Cooling has most often been accomplished with water sprays. Dilution with cold air can be used, but the increased gas volume adds greatly to the expense of air pollution control. The newest systems incorporate boilers for heat recovery. If water is inexpensive, and if the pollution control device performance is not inordinately temperature sensitive (e.g. scrubbers), simple water flow controllers or even manual valves to control water to the sprays may be sufficient, if accompanied by temperature indicators and alarms. In many cases, as for cooling prior to electrostatic precipitators, more sophisticated temperature control is required, such as flow control of water rate in response to temperature measurements. A control schematic is shown in Figure 43.

Flyash Recovery Control. Controls are essential, but vary with the type of pollution control system(s). For example, a venturi scrubber may operate with a fixed amount of water, and an air flow between the limits set by the maximum induced draft fan capacity, and by the necessity for maintaining sufficiently high flow and pressure drop to insure efficient particulate control. One method of controlling venturi scrubber operation uses an air bleed damper to maintain scrubber pressure drop.

In addition to gas temperature control, an electrostatic precipitator normally requires controls for voltage, rapping, hopper temperature, and ash discharge. The control systems are usually supplied by the manufacturer.

Wastewater Control. Controls are normally required for at least pH and discharge and recycle flow rates, and in some cases, temperature. These may be necessary to meet pollution regulations, scrubber and cooling requirements, and to minimize corrosion. Other wastewater properties are usually monitored by laboratory tests.

Indicating and Recording Instrumentation. Indicating and recording instruments are required for supervision of operation, troubleshooting, and record keeping. These include, for example:

Pressures

1. Underfire air duct
2. Overfire air duct
3. Furnace combustion chamber
4. Furnace outlet
5. Flyash collector
6. Inducud draft fan inlet

Temperatures

1. Water leaving feed chute
2. Furnace outlet
3. Other furnace zones
4. Spray chamber outlet
5. Flyash collector
6. Stack

Flows

1. Underfire air (to each section, if separated)
2. Overfire air
3. Water to cooling sprays
4. Water to scrubber
5. Water to flyash hoppers
6. Recycle water to quench

Alarms

Alarms which should be included are:

1. High temperature - charging hopper
2. High temperature - stoker bearings
3. Low pressure - underfire air duct
4. Low pressure - overfire air duct
5. High temperature - furnace
6. High pressure - furnace
7. High temperature - flyash collector
8. Low temperature - flyash collector
9. Low water pressure
10. High temperature - stack

11. Low temperature - stack
12. Low pressure - instrument air
13. Conveyor stoppage
14. Low pressure - cooling water supply
15. High temperature - ID fan bearings
16. High reading - smoke detector

The above alarms are meant as examples. Two or more times this number may be used in a modern incinerator, particularly when steam is produced. Alarms should contain both a visual and a siren feature, with the latter requiring manual shutoff. Alarms are meant to induce operator attention, and response when necessary in accord with written instructions and his training to handle unusual situations.

Other Instrumentation. Depending on the degree of safety, automation, and record keeping desired, and environmental requirements, extensive additional control and instrument systems may be incorporated:

1. Smoke density recorder
2. Measurement of ambient air temperature, barometric pressure, wind velocity and direction
3. Emergency systems e.g. in the event of power, instrument, dust collector, or fan failures, excessive temperatures, and fire detection control
4. Environmental and ventilation systems e.g. for fugitive dust control, and waste water treating
5. Cascade control systems
6. Computer control
7. Automatic weighing
8. TV monitoring of combustion flames (color), smoke stack emissions, plant entrance grates, and critical conveyors
9. Stack gas oxygen monitor
10. Stack gas combustibles monitor

In addition, a laboratory is useful for refuse, residue, flyash, water, and wastewater analyses, and in some cases for specification and quality control of materials purchased.

As seen in Table 49, an example of an incinerator instrument list, a rather extensive array of devices can be used to achieve proper control, even without steam generation or resource recovery.

The addition of a steam boiler to the incinerator increases the instrumentation requirements. Controls for feedwater treatment and flow, steam pressure, steam temperature (if superheated), steam drum level, steam flow, condensers, and appropriate safety devices are required. Tube metal temperatures are particularly important because of potential corrosion problems. Controls are required for soot blowers, which are usually specified for tube cleaning, and for pump and fan drives where steam is used. A reference text should be consulted for typical control requirements for steam boilers.[1]

Table 49

MONITORING EQUIPMENT[9]

MEASUREMENTS

Flue Gas:
- Flue gas flow rate recorder . . . .
- Carbon dioxide analyzer and recorder . . . . .
- Oxygen analyzer and recorder . . . .
- Water vapor concentration recorder with infrared sampling and conditioning equipment . . . .
- Stack emission particulate loading recorder including continuous sampling system . . . .
- Temperature recorder, 24-point, 1-1 point with chromel-alumel thermocouples . . . .

Process Water:
- Water flow rate recorder . . . .
- pH analyzer and recorder-2 points . . . .
- Temperature recorder-6 point . . . .
- Turbidity recorder with flow chamber, light source, and transmitter

Combustion Air:
- Underfire air and overfire air flow recorders with special duct work arrangements for flow measurements . . . .

Table 49 (Continued)

MEASUREMENTS

Temperature recorder (12 positions) for underfire, wall cooling, and overfire air . . . .

Pressure recorders for draft and pressures in air zones, also including furnace, dust control equipment, and stack conditions . . . . . .

Forced draft fan motor current recorder . . .

Furnace:

Refuse feed rate recorder .

Temperature recorder-24 point with chromel-alumel thermocouples for refractory temperatures to 2,000° F . . . . .

Temperature recorder-24 point with platinum-rhodium thermocouple for refractory and face temperatures to 2,700° F . . . . . .

Temperature recorder-6 point with radiamatic elements in sileramic tubes for gas temperature measurements . . . . .

Feed preparation and resource recovery, such as magnetic metal separation, shredding, air density separation, glass separation, aluminum separation and other new developments require very special operational controls as well as conveying systems controls, fugitive particle control, and other controls somewhat akin to the mining industry.

The use of pretreated refuse as a supplementary fuel in pulverized coal suspension-fired boilers for power or steam generation, now under development, will require feed preparation controls as indicated above. However, it is expected that the boiler controls will remain essentially the same, since refuse is expected to be limited to 10 to 20 percent of the total fuel requirements.

Pyrolysis Process Instrumentation

Pyrolysis processes are in various stages of development, as explained in Chapter XI. Due to the complexity of these processes, involving combustible fuel products, the instrumentation and control requirements are likely to be quite extensive. Since all the processes are, at this time, proprietary in nature, little information is available on instrumentation. It is likely that the process owners will supply a design package including necessary instrumentation and controls.

Feed preparation and resource recovery practiced with pyrolysis will likely be similar to that practiced with incineration. Some idea as to the potential complexity of the pyrolysis step can be gotten by referring to typical instrumentation for chemical reactors and pyrolysis furnaces.

Types of Instruments and Controls. Each parameter that is measured or detected can be indicated and/or recorded locally at the point of detection; transmitted to a remote indicator or recorder; or the measurement can be used to actuate local or remote control or alarm circuits. Multipoint recorders to monitor 6 to 24 temperatures are in widespread use for cost reasons, in spite of disadvantages in response time and opportunity for misinterpretation as compared to separate instruments. Numerous choices are available for each instrument function depending on the service required. For example, the choice of a temperature sensor depends upon applicable temperature ranges, accuracy, physical size, stability, repeatability, response time, sensitivity, interchangeability, maximum distance to readout, and suitability for the control or alarm devices to be used. The application of various types of sensing and measuring devices to thermal processing equipment is outlined in Table 60.

Just a few of the other instrumentation choices to be made are related to pneumatic vs. electronic controls, including consideration of the cost of a clean dry air supply for pneumatic control; type, size, and speed of indicating and recording instruments; modes and mechanisms for control; remote vs. local instrumentation; control room layout; and selection of mechanisms for the control action, including control valves, dampers, motor speed controls, and the like. Pneumatic controls are much more widely used than electronic controls, but the increasing availability of electronic

Table 50

TYPICAL INSTRUMENTATION TO BE CONSIDERED FOR THERMAL PROCESSES

APPLICATIONS	MEASURING DEVICES
Very high temperatures for combustion zones (greater than 1100 C)	Pyrometers (infrared, radiation, optical), platinum/rhodium thermocouples (sheathed)
High temperatures for incinerators and pyrolysis reactors (600-1100 C)	Chromel/alumel, chromel/constantan, and stainless steel thermocouples, resistance temperature detectors (platinum)
Moderate temperatures for ambient measurements, water, driers, steam (20-600 C)	Iron/constantan thermocouples, resistance temperature detectors (platinum, nickel, copper), filled elements, bimetallic thermometers, liquid-in-glass thermometers, thermistors
Liquid levels for quench and wastewater tanks, feedwater and steam drums	Floats, displacement sensors, ultrasonic detectors, gauge glasses, differential pressure detectors, tape level gauges
Solid levels for feed hoppers, flyash hoppers	Capacitance probes, ultrasonic detectors, radiation gages, tape level gauges
Draft pressures for furnaces, ducts, air pollution control devices, stacks (0.1 to 1.1 atmospheres absolute) and differential pressures for flow and level determination	Diaphragms, bellows, manometers, inclined gauges, bell-type gauges
Air, steam, water pressures (greater than 1.1 atmospheres absolute)	Bourden tubes, diaphragms (6-20 atmospheres maximum), bellows (6-50 atmospheres maximum)
Air, flue gas, fuel gas, and steam flows	Orifices, venturi tubes, flow nozzles, pitot tubes, elbow taps - with differential pressure measurement
Low gas flows for special purposes	Rotameters, laminar flowmeters, gas displacement meters
Liquid flows for fresh water, boiler feed water, wastewater, fuel, neutralization, water sprays	Orifices, venturi tubes, flow nozzles, weirs, rotameters, turbine flowmeters, liquid displacement meters, metering pumps, self-contained regulators

Table 56 (Continued)

APPLICATIONS	MEASURING DEVICES
Electrical characteristics for motors, heaters, electrostatic precipitators, lighting	Voltmeters, ammeters, watt meters, spark meters (electrostatic precipitators)
Motion for fans, stokers, conveyors	Tachometers, counters
Position for dampers, valves, controls	Deflection meters
Visual observation of furnace and reactor interiors, loading and unloading operations, conveyor belts, stack effluents, plant entrances	Observation ports, mirrors, closed circuit television
Analyzers for stack and waste water emissions, fuel products, ambient air quality	Multitude of specialized instruments available - some additional discussion in Chapter XIV
Weight of full and empty trucks (raw refuse, resource recovery products, residues), crane bucket contents	Platform scales (discussed in Chapter VII), load cells
Vibration of fans and other rotating devices	Probes (transducers) to measure displacement, velocity, or acceleration with readout and preferably with warning and shutdown capabilites
Electrical measurements for power current, voltage in fan, pump, and other motors, electrostatic precipitators, control systems	Wattmeters, ammeters, voltmeters, spark meters (precipitators)

controls and their adaptability to computers without transducers to convert pneumatic signals, may increasingly justify their use. Instrumentation design is the function of instrumentation specialists working for the design engineering organization, guided by the needs of the client and by the recommendations of the major equipment manufacturers.

Operational Problems Involving Instruments and Controls. An instrumentation system which is carefully thought out and well designed with cost-effectiveness choices, should result in a successful operating facility. However, proper installation, routine calibration, and maintenance are also essential for accurate, safe, and reliable operation. Contract maintenance service should be considered if staff personnel are not appropriately qualified, but operators should be trained for every day problems such as chart changing, inking, and simple part replacement.

Enclosed or protected instruments will have less problems from dust, dirt, water, and abuse. Sensing devices will require protection in certain services, such as in the combustion chamber and flue gas ducts. Consideration may be given to duplication of critical sensors and/or instruments. Pneumatic instruments require dry, clean air. Especially good drying is essential where air lines are exposed to ambient conditions in cold climates. Virtually all instruments and controls are directly or indirectly dependent on electrical power. The system should be "fail-safe" in the event of a power outage or other instrument failure.

Of course, an inventory of ink, charts, and spare parts should be maintained and used. From an operator standpoint, simplicity and ruggedness are desired. Dampers, for example, should be capable of withstanding the abusive gases, have fine adjustment, lock in place, and have remote bearings, if possible.

TV monitoring of unmanned and critical areas can reduce manpower needs and minimize down time, damage, and unsatisfactory performance. It has been used to monitor conveyors for jams, fire boxes for good combustion, automatic weigh scales, and stacks for smoke. Difficulties may be encountered in keeping camera lenses clean in dirty services; similar problems may be encountered with smoke meters. Air purging can help overcome this problem.

Future Needs. With the advent of complex sophisticated thermal processing systems, including steam generation, pyrolysis, resource recovery, and pollution controls, instrumentation and control systems needs become correspondingly more extensive. As in other process systems, TV monitoring and computer control should become useful tools.

The most important single undeveloped area appears to be the control of parameters dependent on the nature of the solid waste. For example, feed rate, and underfire air cannot be automatically controlled because of a lack of a sensor for refuse moisture, heat of combustion, and burning rate.

Process instrumentation hardware and design engineers should be utilized to provide systems that adequately meet the operational and performance requirements for the least overall initial operating costs.

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CHAPTER XIII

LIQUID AND SOLID EFFLUENTS AND THEIR CONTROL

Even the most efficient thermal processing of solid wastes results in undesirable effluents. Incineration effluents are primarily inorganic, in the form of particulate and other chemical emissions in gaseous effluents, dissolved and suspended materials in aqueous effluents, and solid residues. As will be discussed in a subsequent section of this Chapter, pyrolysis effluents may also be high in organic materials.

The unit processes which are commonly used in incinerator plant design and the associated discharges to air, land and water are shown in Figure 44. This Chapter describes discharges to land and water, while air emissions are treated in Chapter XIV, "Air Pollution Control." The recovery of useful materials from residues is covered in Chapter XVII.

Handling and Storage Effluents

Dumping, handling, and storage of municipal solid waste produces dust and litter, as well as odors. Therefore, the storage pits and tipping floor are areas which deserve major attention, if problems from these sources are to be averted.

Litter, consisting mainly of paper and other debris, results from accidental spillage in and around the plant. Dumping of refuse produces airborne dust which may be either organic or inorganic. Obnoxious odors result primarily from the putrefaction of food wastes and other organic materials. Odor problems are especially troublesome when waste is held in the storage pits for long periods. The combined effect of dust and odors, if uncontrolled, create a condition which is very unpleasant for employees who work in these areas. Dust can also adversely affect instrumentation and controls, and mechanical and electrical equipment. Litter is primarily a nuisance which creates an untidy appearance of the plant and grounds.

Frequent sweeping of the tipping floor effectively removes litter. Cleaning of the storage pit is facilitated if the pit is divided into sections. Each section of the pit should be emptied at frequent intervals so that putrescibles may be removed. The tipping floor and pit floor should be washed with cleaning-disinfecting solutions for control of odors and insects.

Wetting the solid waste in the storage pit by use of water sprays is the most frequently used means of dust control. Some incinerator plants control dust and odors in the pit by locating intake ducts for the forced draft fans within the pit area, sweeping these pollutants into the fan intake and then into the furnace, thus preventing them from being dispersed throughout the plant.

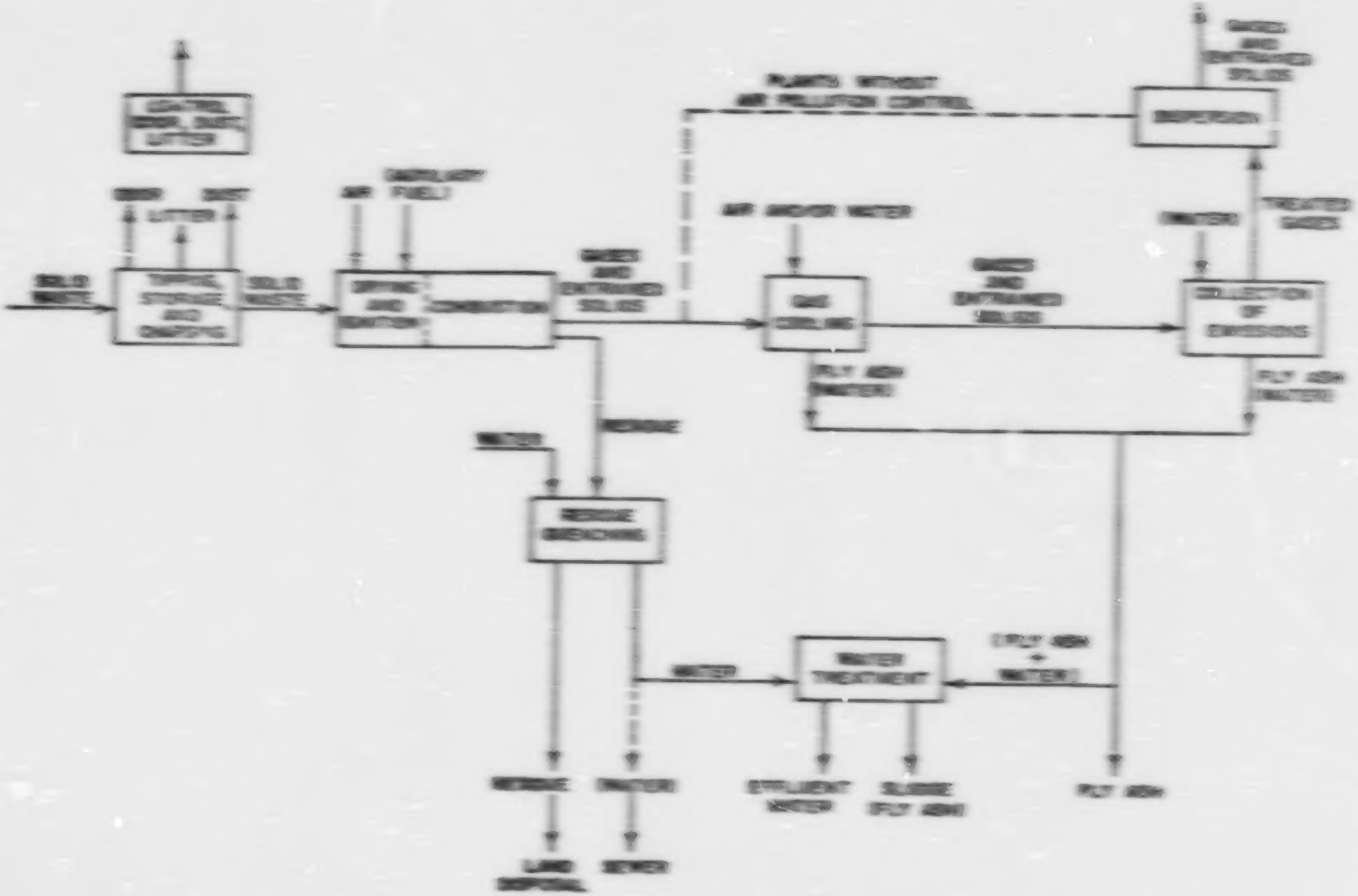
SOLID WASTE
TIPPING, STORAGE AND CHARGING
ODOR
LITTER
DUST
CONTROL ODOR, DUST, LITTER
SOLID WASTE
AIR
(AUXILIARY FUEL)
DRYING AND IGNITION
COMBUSTION
GASES AND ENTRAINED SOLIDS
PLANTS WITHOUT AIR POLLUTION CONTROL
AIR AND/OR WATER
GAS COOLING
GASES AND ENTRAINED SOLIDS
FLY ASH (WATER)
(WATER)
COLLECTION OF EMISSIONS
FLY ASH (WATER)
TREATED GASES
DISPERSION
GASES AND ENTRAINED SOLIDS
RESIDUE
WATER
RESIDUE QUENCHING
WATER
(FLY ASH + WATER)
WATER TREATMENT
RESIDUE
(WATER)
EFFLUENT WATER
SLUDGE (FLY ASH)
FLY ASH
LAND DISPOSAL
SEWER

FIGURE 44. DIAGRAM OF THE INPLANT SYSTEMS BASED UPON DRY FLY ASH COLLECTION AND CONVEYING FROM COOLING AND COLLECTION OPERATIONS. ALTERNATIVES FOR WET COLLECTION AND CONVEYING SHOWN IN PARENTHESES.[7]

The future may bring greater emphasis on the design of enclosed material handling systems to permit positive exhaust of air through purification systems. When such provisions are made, dust laden air can be processed in bag filters or other means to prevent release to the atmosphere. Odors in exhaust air can sometimes be eliminated by addition of ozone or by passing the air through beds of activated carbon.

Provision should be, but is not always, made for treatment of water used for dust control, and for washdown of the tipping floor, charging floor, and storage pit. Runoffs of this type are frequently drained directly to sanitary sewers or surface waters. Preferably, all these wastewaters should be treated with the process wastewater.

Incinerator Residues

Incinerator residues are defined here as the solid materials remaining after combustion. Classifications of residue include grate residue, grate siftings and flyash. The quantity of residue produced, when front end resource recovery is not practiced, generally ranges from 20 to 35 percent by weight of the original refuse, but usually only about 5 to 15 percent by volume. The proportions of grate residue, siftings, and flyash depend to a large extent on the design of the incinerator and of the air pollution control equipment.

Grate Residue and Siftings. Residue discharged from burning grates consists of ash, clinkers, cans, glass, rocks and unburned organic substances. Grate siftings are similar materials which have become sufficiently reduced in size to filter through the grate openings or to drop between the grate and the furnace wall. Bulk densities of grate residue and siftings, as measured in one test, were 640 and 1056 kilograms per cubic meter (1040 and 1780 lbs/cubic yard), respectively.[4]

Composition of combined incinerator residues from three sources are given in Table 51.[4] Since seawater was used for sluicing at the Oceanside plant, a portion of the residue measured was contained in the sluice water runoff. The Oceanside and Stamford plants employed rocking grates with comparatively large grate openings. The Washington, D.C. data were obtained from five batch fed plants.

Siftings may be recovered wet or dry depending on the incinerator design. However, most grate residues are recovered from quench water. The wet residues are drained as they are conveyed from the furnace. The siftings and wet residue are usually trucked to nearby landfill sites. These should be, but are not always, water tight trucks. If resource recovery is practiced, for example, magnetic recovery of ferrous metals, the separation equipment is built into the incinerator plant.

Flyash. As explained previously, flyash is that portion of the solid residue from combustion carried by the combustion gases. It arises as a solid effluent after recovery from flue gases using various air pollution control

Table 61

COMPARISON OF RESIDUE COMPOSITIONS[9]

	Oceanside, Wt. %	Stamford, Wt. %	Wash., D.C. Wt. %
Metals & Mill Scale	19.85	23.58	29.5
Glass	9.48	36.63	44.1
Ceramics, Stones	1.61	4.73	2.0
Clinkers	24.11	17.23	--
Ash	16.10	14.08	15.4
Organic*	1.89	3.75	9.0
Residue Solids in Conveyor Runoff Water	27.06	0	--
	100.0	100.0	100.0

* Good measure of burnout

devices. The flyash consists of dust, cinders, soot, charred paper and other partially burned materials. Most flyash particles range in size from 120 to less than 2 microns.[5] Size distribution within this range is extremely variable.

Flyash from efficient incineration is predominantly inorganic and consists largely of the oxides or salts of silicon, aluminum, calcium, magnesium, iron and sodium.[4] Compounds of titanium, barium, zinc, potassium, phosphorous and sulfur[4] may be present in small amounts. Trace quantities of many other elements may also be present.

Dry flyash is difficult to handle and can be easily picked up and scattered by the wind. Therefore, it should be stored in closed containers. If open storage is necessary, barriers should be erected and the surface of the ash pile kept moist with water sprays. Transportation to the final disposal site in covered trucks or closed containers is recommended. Some plants reduce dust problems by intermixing ash with wet residue, or by topping off the truck with a layer of wet residue.

Land Disposal of Residue. Although incinerator residue is comprised mainly of insoluble inorganic material, the small fractions of soluble inorganics and organics require land disposal methods usually classified as sanitary landfilling. Guidelines for sanitary landfill site selection, design, and operation are available.[6,7]

Sanitary landfill practices are designed to avoid pollution of surface and ground waters, odors, rodents, insects, and other vectors requires spreading the solid wastes in thin layers, compacting to the smallest practical volume, and applying a compacting cover material at the end of each operating day, or more often. Practices for a landfill disposing of only incinerator residue may differ from disposing of mixed municipal solid waste because of the lower organic content (causing less gas formation) and higher density (requiring less compaction). However, measures designed to avoid water pollution, for example, the use of impervious membranes as a barrier against groundwater intrusion and leaching from rainfall, interception of rainfall and surface waters, and/or treatment of leachate, will most likely be similar for an incinerator residue landfill.

The amount of landfill leaching which will occur is dependent upon the composition of the residue, its permeability, and the degree of fusion of external and internal surfaces. Also, when water contacts the residue, it almost invariably picks up fine solid particles which contribute to increased levels of suspended solids, turbidity, and BOD (from organic content) in the water. Because the presence of organics in the residue may lead to particularly harmful environmental effects, the degree of burnout during incineration is an important variable.[8]

There is a good deal of disagreement regarding the efficacy of landfill for disposal of incinerator residues. It has been determined that the water soluble portion of the residue amounts to approximately 4.75 to 5.75 percent of the dry weight of material placed.[8] Data are generally not available, however, on the extent to which this material is removed by leaching or the rate at which leaching takes place. Leaching tests conducted in Germany[10] suggest a relatively low mineral content of water after the elutriation of finely ground incinerator residue with distilled water. The initial eluate contained approximately 115 mg/l minerals, and the tenth eluate contained less than 20 mg/l. By comparison, similar tests conducted using composted refuse produced concentrations of calcium and magnesium (as CaO and MgO) which were an order of magnitude higher than in the residue leachate. The explanation proposed was that as the residue reaches a combustion temperature of 800 C, the salts are converted to oxides which are insoluble, or only slightly soluble. Also, it was noted that glassy insoluble substances are formed with the silica present (e.g. calcium silicate and magnesium silicate). It appears that additional testing is needed to determine the extent of the leaching problem and to develop control methods.

Incinerator Wastewater

The process wastewater from incinerator plants is contaminated by both dissolved and suspended materials. To prevent pollution of streams and underground water, some form of treatment is usually required prior to discharge.

It is important to distinguish between the treatment required prior to discharging to a sewer system which sends its water to a municipal treatment plant, and discharging directly to the environment, for example, a marsh, river, or tidal basin. In the former instance, minimal treatment such as settling and possibly pH adjustment may be adequate. In the latter, the treatment system must be designed to remove the objectionable contaminants to a level consistent with Federal, state and local water quality discharge regulations.

Process Wastewater Sources and Quantity. The sources of process water from an incinerator plant include feed chute water jackets, furnace wall cooling, residue quenching, residue and flyash conveying, wet scrubbers, wet baffles, wet bottoms, and settling chambers. Intermittent uses include storage pit sprays, and floor and pit washings.

The quantity of water used in incinerator plants varies widely, depending upon the extent and mode of water uses in air pollution control equipment, residue conveying, and stack gas temperature control. An individual estimate must be made for each incinerator design, but, based on previous estimates[11,12] the quantity of water discharged can exceed 12 tons per ton of solid waste processed (2900 gallons per 2000 lbs) when scrubbers are used. This quantity may be cut by a factor of two in the absence of scrubbers, and to much smaller values when extensive recycle is used, for example, as little as 2 to 3 tons per ton of waste.[12]

Other Incinerator Wastewaters. Other than the process wastewater, an incinerator plant will discharge the usual sanitary wastes, and runoff waters. The sanitary wastes are usually discharged to a sanitary sewer for treatment in the municipal sewage plant. The quantity can be estimated from the number of employees.

Runoff water varies with washdown procedures, precipitation, terrain, and soil characteristics. The necessity to deal with surface and runoff waters in residue landfills was discussed in the "Incinerator Residue" section. Although runoff water is less of a problem where only the incinerator or other thermal processing unit has to be considered, it is nevertheless a real one. Water can be contaminated by the litter and dust which invariably is associated with solid waste handling.

A preferred solution to the problem is to direct storm sewer effluents from handling areas to the process water system, but regulations do not always permit this approach if the process water is discharged to a municipal treatment plant. In that case, onsite treatment might be required. Uncontaminated runoff waters can be handled in storm sewers.

Wastewater Quality. The quality of water discharged from the various process units also varies widely from one plant to another, and daily variations occur within the same plant. Variations result from non-uniformity of solid waste composition and changes in water usage. Some important wastewater characteristics are:

Temperature
Dissolved oxygen (DO)
Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Hydrogen Ion Concentration (pH)
Alkalinity
Hardness
Total Solids
Total Dissolved Solids
Suspended Solids
Settleable Solids
Phosphates
Nitrates
Fluorides
Heavy Metals
Odor

Water analyses for several incinerator plants, including quench water, scrubber water and final effluent water are given in Table 52.[71] The extent of variation in the amounts of each contaminant is apparent. Residue quench water, which may be either basic or acidic, contains moderate concentrations of dissolved minerals, and often high concentrations of suspended solids. Temperatures are not exceptionally high, ranging from 20 to 54 C (68 to 130 F), but cooling is sometimes required.

Acidic conditions usually prevail in scrubber water. Dissolved material content is much higher than in quench water, due to combined effects of low pH and the practice of recycling a portion of this water back to the scrubber. Average values for suspended solids in the scrubber water are lower than those presented for quench water. This may be related to the design of the scrubber, which permits settling prior to reuse of the water. The temperature of scrubber water is considerably higher than for quench water, and ranges from 28 to 74 C (82 to 165 F).

Combined wastewater from all sources may be either acidic or basic in nature, as shown in Table 52, which indicates a pH range of from 4.5 to 9.9. Dissolved solids vary from 320 to 4,060 mg/l, presumably depending upon the extent to which water is recycled. Suspended solids content ranges from 40 to 580 mg/l, the lower values representing water sampled after settling has taken place. Temperatures ranged from 18 to 52 C (65 to 125 F), the higher values being of concern from the standpoint of thermal pollution and dissolved oxygen depletion of the receiving water.

Data in Table 53 for cooling-expansion chamber spray water show trace contaminants such as fluoride, iron and ABS (alkyl benzene sulfonate).[15] It should be noted that the fluoride value of 7.8 mg/l is significantly higher than the permissible level for public water supply (1.2 mg/l). Other data for minor contaminants in scrubber water are shown in Table 54. These include cyanide, phenols, iron, chromium, lead, copper, zinc, manganese, aluminum, and barium. Of these, all but total chromium exceeded the Florida quality standards for incinerator effluents. Additional data in Table 55[15] show the effect of pH in flyash water on the concentration of various metal ions found in the water sampled. In almost every instance, the water having the higher acidity (lower pH) contained larger amounts of metals.

Data on oxygen demand characteristics of incinerator water are seldom reported in the literature. One source[15] reports 5-day BOD determinations (expressed in mg/l) for water from the following sources: residue conveyors - 618, 750, 560, 605, (4 different incinerator plants); ash hopper - 700; flyash disposal - 3.2; and lagoon - 54. BOD of the combined waste water from the incineration of municipal solid waste would be expected to be similar to that of domestic sewage, averaging about 200 to 300 mg/l. Although good incinerator performance results in high burnout of organics and thus lower BOD in quench, scrubber, and other process waters, some BOD content of untreated waters is to be expected. Some bacterial content can also be expected as shown by a limited study of incinerator wastewaters from a 1.9 metric ton per hour (50 tons/day) batch feed incinerator and from an 11.3 metric ton per hour (300 tons/day) continuous feed municipal incinerator.

The BOD and bacterial contents of the wastewater provide a potential for odor problems, especially where wastewaters are impounded and not sent directly to treatment plants. Although not commonly necessary, chlorine,[15] ozone,[16] quaternary ammonium phenate,[15] and other chemicals can be used for odor control. The quantity of such chemicals required would be greatly reduced by pretreatment, e.g. by biological treatment.

Wastewater Treatment. There is an increasing trend in the design of process water systems to recycle at least a portion of the water to satisfy other process water requirements within the plant. Minimum wastewater treatment systems recommended for solid waste processing plants include settling basins or lagoons and pH adjustment. Oil skimmers and retention baffles may be used in the basin to handle leakage or spillage from machinery lubricators, the machine shop, and hydraulic systems.

Automatic pH control systems with a measurement probe and electronic controls which proportion the feeding of chemicals are useful. Chemicals

Table 52

TYPICAL WASTEWATER ANALYSES[11]

	Quench Range	Scrubber Range	Final Effluent Range	Final Effluent Avg.
pH	3.9-11.5	1.8-9.4	4.5-9.9	---
Temperature, °C	20-54	28-74	18-52	32
(°F)	(68-130)	(82-165)	(65-125)	(90)
Suspended Solids, mg/L	140-1860	90-1350	*40-580	210
Dissolved Solids, mg/L	360-2650	520-8840	320-4060	1190
Total Solids, mg/L	610-3960	610-9160	610-4200	1400
Alkalinity, mg/L $CaCo_3$	90-720	0-80	15-310	135
Chlorides, mg/L	98-850	180-3540	95-1710	455
Hardness, mg/L	95-960	190-3430	100-480	240
Sulfates, mg/L	25-830	24-1830	33-1685	390
Phosphates, mg/L	0.5-58	3-90	1-67	14

* After settling.

Table 53

CHEMICAL QUALITY OF COOLING-EXPANSION CHAMBER WATER DISCHARGE AT INCINERATOR NO. 1[17]

Constituent		Test 1	Test 2	Test 3	Test 4
pH		7.9	5.5	3.5	6.2
Alkalinity	($CaCO_3$)	35.0	9.0	0	10.0
Nitrate	(NO_3)	1.5	1.90	2.00	2.00
Phosphate	(PO_4)	0.2	0.61	0.39	0.17
Chloride	(Cl)	582.0	453.0	567.0	422.0
Fluoride	(F)	4.5	6.40	4.40	7.80
Calcium	(Ca)	330.0	220.0	255.0	250.0
Sulfate	(SO_4)	338.0	238.0	188.0	300.0
Sodium	(Na)	85.0	63.0	73.0	60.0
Potassium	(K)	27.0	14.8	16.7	14.0
Iron	(Fe)	1.6	0.93	5.77	0.50
ABS	(ABS)	1.91	0.1	0.19	0.21

All values are expressed in mg/l except pH.

Table 64

SCRUBBER WATER CHEMICAL CHARACTERISTICS[13]

Constituent		Quality Standard†	Raw Water	Scrubber Effluent
Iron	(Fe)	0.3	0.35	1.65
Cyanide	(Cn)	0	0.21	5.19
Total Chromium	(Cr)	1.0	0.0	0.13
Lead	(Pb)	0.50	0.0	1.30
Phenols		0.005	0.005	1.721
Copper	(Cu)	0.05	0.08	0.10
Zinc	(Zn)	1.0	5.0	2.4
Manganese	(Mn)	---	0.0	0.30
Aluminum	(Al)	---	0.18	20.6
Barium	(Ba)	---	0.0	5.0

† State of Florida quality standard for incinerator effluents. Data from Broward County, Florida incinerator. All values are expressed in mg/l.

Table 55

EFFECT OF pH ON CATION CONCENTRATION-FLYASH WATER, INCINERATOR "A"[14]

Cations	Concentration (parts/million)	
	pH = 3.4	pH = 6.30
Ca	913	718
Na	1621	1621
K	212	173
Mg	83	64
Zn	78	52
Pb	19	10
Al	32	14
Mn	4	3
Sr	1	1

used to adjust acidic wastewater include lime, soda ash, and caustic soda. Sulfuric acid is generally used to reduce pH when the wastewater is alkaline. As noted in the section on "Wastewater Quality," scrubber water is usually acidic, while overall wastewater may be acidic or basic.

Consideration should be given to reusing water which has been thus treated to reduce the fresh makeup water required, and to minimize the quantity of contaminated water discharged. The quality of treated water from the settling basin will often be adequate to permit reuse in flue gas scrubbing (after filtering to prevent nozzle plugging), residue quenching, ash conveying, and for utility water used for washdown, etc. Sufficient fresh makeup water may be needed to prevent precipitation of scale in the piping and other water handling equipment. A schematic drawing of a simple treatment system is shown in Figure 45.

It is desirable to be able to discharge wastewater to existing municipal treatment plants, but, where this is not possible, maximum recycle and a greater degree of onsite treatment should be practiced. A wastewater treatment system which goes beyond simple settling and neutralization may include flocculation, biological treatment, and filtration. These treatment steps, which will be outlined here, are used for many industrial plants though they have not been required for municipal incinerators.

Chemical flocculation involves the use of coagulants and coagulant aids to remove inorganic and organic contaminants. Alum is frequently used as a coagulant, and lime may be added to produce dense floc, which settles readily, and to simultaneously increase pH. Coagulant aids include polyelectrolytes and activated alumina. Suspended solids can be reduced to 20 mg/l in a well designed, carefully operated chemical treatment system. Dissolved solids concentrations will also be reduced substantially, particularly when calcium, magnesium, manganese, and iron are initially present in high concentrations. Chemically aided flocculation is also employed as a means of reducing the concentration of heavy metals such as lead, chromium, copper, zinc, aluminum, barium, lead, manganese, and mercury.

Biological treatment depends upon contacting the wastewater with bacteria and other biological organisms to effect a metabolic breakdown of the organic substances present in the water. This can be achieved in various types of equipment, with perhaps the activated sludge process and the trickling filter being the most common. In activated sludge, the biological organisms are kept in suspension throughout the wastewater by means of injected air or mechanical turbulence. The trickling filter, by contrast, contains a "fill" or solid matrix to which the organisms are attached and over which the water flows.

The process of choice depends upon capital and operating cost, strength of the waste to be treated, degree of purification required, availability of space, and other factors. Toxic materials including phenols, cyanide, and pesticides can be removed to varying degrees by biological treatment. However, the design must provide positive means of control, such as equalization tanks, to insure that the concentration of these materials entering the unit are kept low enough to prevent upset to the biological organisms.

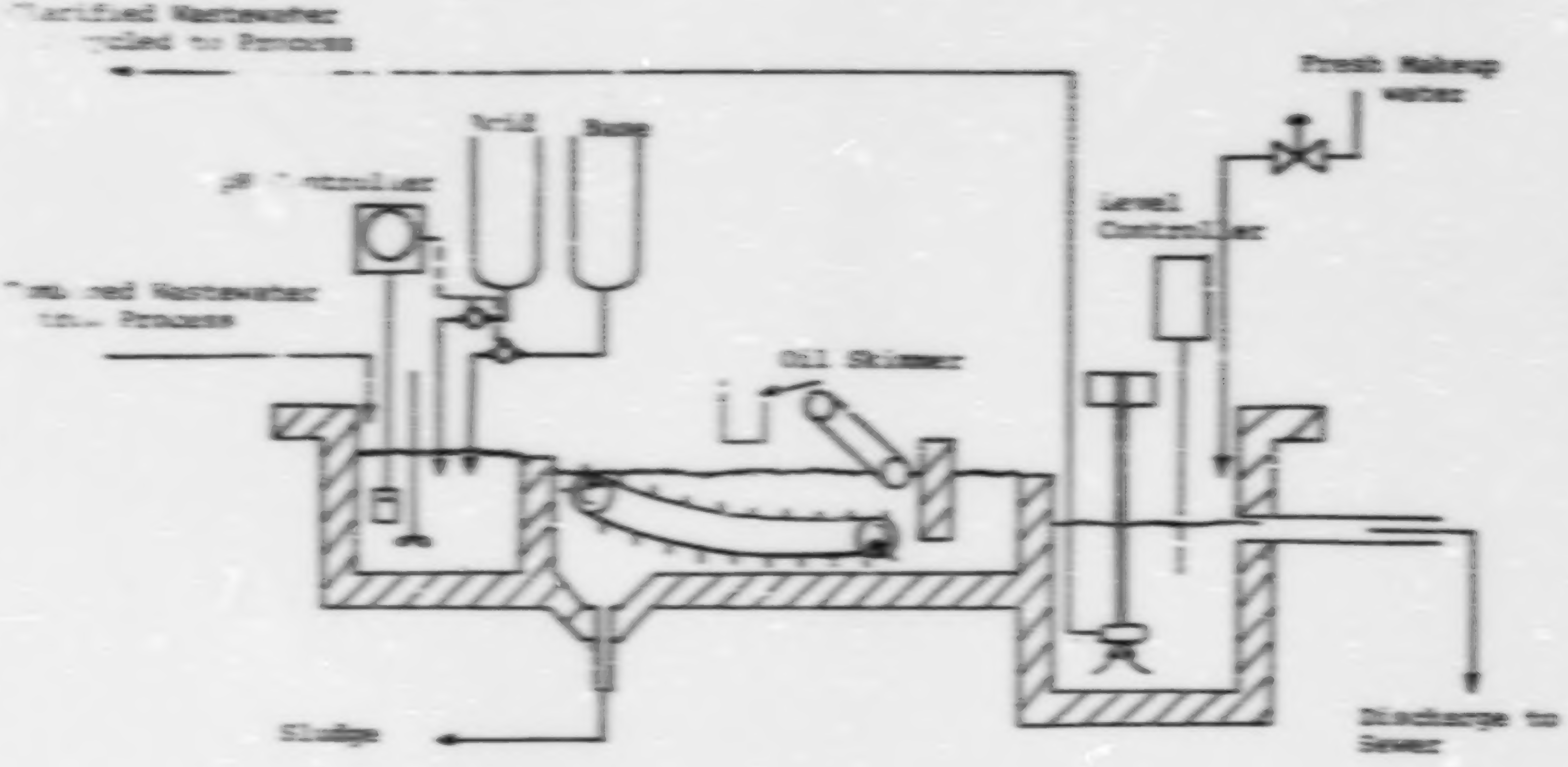
Clarified Wastewater
Recycled to Process
pH Controller
Acid
Base
Combined Wastewater
from Process
Oil Skimmer
Level
Controller
Fresh Makeup
water
Sludge
Discharge to
Sewer

FIGURE 46. WASTEWATER TREATMENT SYSTEM FOR WASTEWATER DISCHARGED TO A SEWAGE TREATMENT PLANT

If biological treatments were contemplated, segregation of incinerator wastewater according to the degree of organic contamination present could be considered. This would permit biological treatment of residue quench water with simpler treatment of water from scrubbers, other air pollution control equipment, and flyash handling, where BOD contamination is low.

Filtration of water by means of granular beds of sand or anthracite is sometimes used as the final step in the removal of suspended matter from water, usually following a settling step. Granular bed type filters are used to polish the effluent from physical/chemical processes and/or biological treatment plants. Removal of 95 percent of the influent suspended solids and 30 percent of the BOD is possible. Addition of chemicals such as clay has been found useful in improving the removal efficiencies of granular bed filters.

Finally, disinfection might be required to allow discharge of the treated wastewater directly to the receiving water. Chlorine has been most commonly used, added in sufficient quantity to leave a 1 or 2 mg/l residual. However, toxic chlorinated organic compounds can be a problem, casting some doubt upon the desirability of chlorine addition. The use of ozone as a disinfectant has been the subject of recent investigations, primarily because toxic byproducts do not appear to be generated. Also, ozone is more effective in removing traces of cyanides and phenol from the water.

Figure 46 is a schematic diagram showing the type of treatment system which might be used where high contaminant removal efficiencies are required. It should be noted that this more extensive treatment results in sludges which must be disposed of, just as is the case with sewage treatment plants. In general, where possible, it is most desirable to maximize recycle after simple onsite wastewater treatment, discharging effluents to the municipal sewer system.

Discharges from Pyrolysis Processes

In recent years, thermal processing techniques have been developed which produce fuels by the pyrolysis of solid waste in an oxygen deficient or reducing atmosphere. In some pyrolysis processes, including the current versions of the Monsanto Process (Baltimore, Maryland plant) and the Torrax Process (Orchard Park, New York pilot plant) the hot fuel gases are burned in a waste heat boiler to generate steam. After combustion, the waste gases are scrubbed with water before being released to the atmosphere. Control of air emissions and treatment of scrubber water pose no special problems which are not encountered in the operation of conventional incinerator plants.

Other processes, including the Occidental Research Company Process (San Diego County, California plant), condense the pyrolytic fuel oil produced. The condensate contains both the liquid oil, and the water which is produced simultaneously during pyrolysis. These separate into an oil phase and a water phase which are physically separated. However, the water phase is highly contaminated with a multitude of water soluble organic compounds such as acids, aldehydes, and alcohols. This contaminated water, which may contain BOD values near 100,000 mg/l, poses serious recovery or disposal problems.

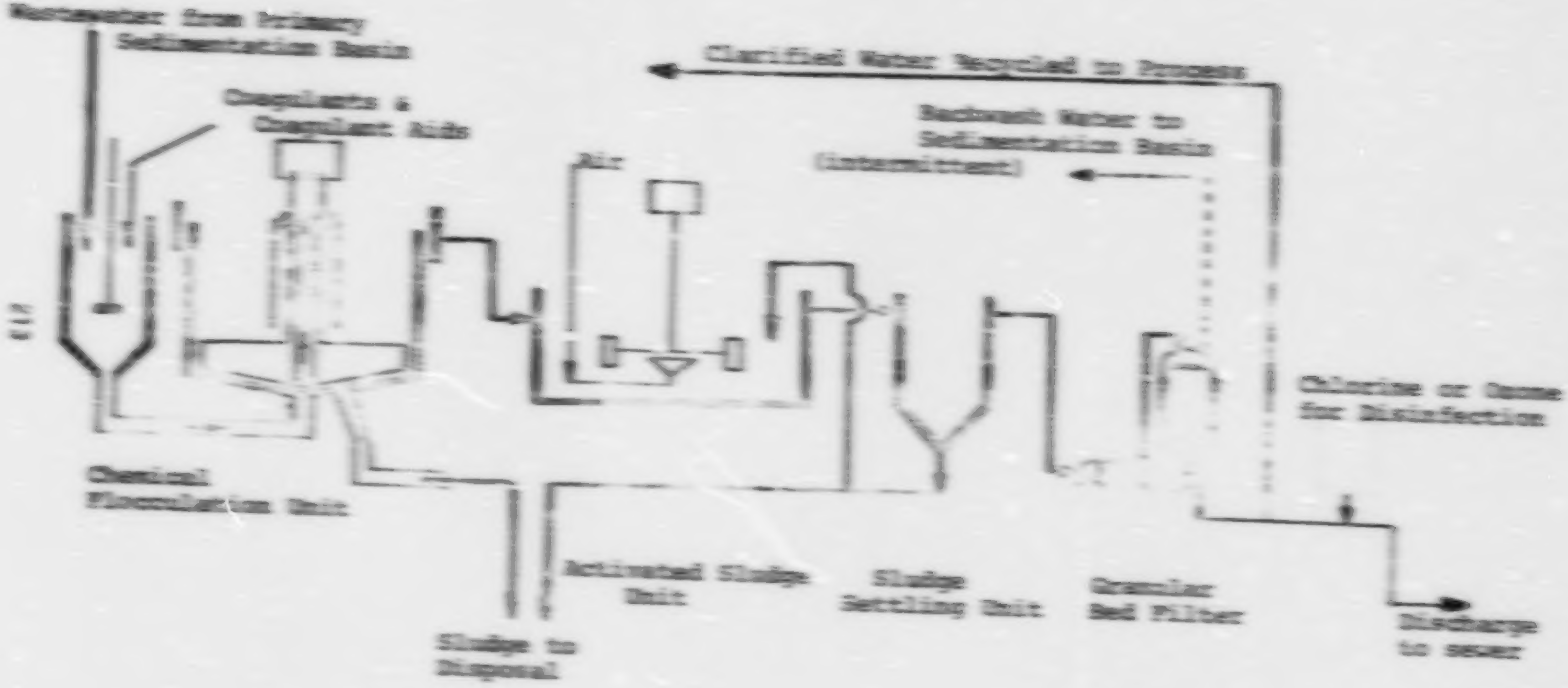
Wastewater from Primary
Sedimentation Basin
Coagulants &
Coagulant Aids
Air
Clarified Water Recycled to Process
Backwash Water to
Sedimentation Basin
(Intermittent)
Chlorine or Ozone
for Disinfection
Chemical
Flocculation Unit
Activated Sludge
Unit
Sludge
Settling Unit
Granular
Bed Filter
Sludge to
Disposal
Discharge
to sewer

FIGURE 46. HIGH EFFICIENCY WASTEWATER TREATMENT SYSTEM

In Occidental's San Diego plant, which is under construction, the aqueous phase will be vaporized and the organic contaminants burned, with a net consumption of energy. A second alternative, which has been considered, is to blend the aqueous condensate with other wastewater and to subject the combined waste to biological treatment. Recovery of the organic compounds from the water phase may be possible, but considerable development work would be required to find a practical and economical method for recovery.

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CHAPTER XIV

AIR POLLUTION CONTROL

Historically, the air pollution problems caused by incineration have been so severe that, in the public eye, "smoke" represents the single most associated image of incineration. However, with current day technology and stringent Federal, State and Local regulations, modern, well-designed incinerators and other thermal processing facilities can be and are socially and environmentally acceptable.

Planning, design, specification, purchase, installation, operation, and maintenance of air pollution control systems require at least as much attention as the furnaces, buildings, and other sections of the facility. Even at this late date in the evolution of regulations and technology for proper control, several recent projects have had major difficulties with air pollution control systems, some requiring major modifications or complete replacement. Particulate emissions are generally of greatest concern, but chemical emissions will also be considered in this discussion.

Most of the information presented here pertains primarily to incinerators, both with and without energy recovery. Special sections are devoted to emerging thermal processing systems such as combined refuse/fossil fuel boilers and pyrolysis.

Uncontrolled Particulate Matter Emissions

Any general discussion of particulate emissions may create confusion, since there is no universally accepted definition of or measurement procedure for "particulate." In an actual situation, careful study of applicable regulations and stack testing are essential. Examples of definitions and test procedures which exist for regulating particulate emissions from municipal incinerators are shown in Table 66.

For purposes of simplicity, particulate emissions which are filterable at approximately 121.1 C (250 F) will be referred to as "dry catch"; particulates which pass through the filter will be referred to as "wet catch"; total particulates equal dry catch plus wet catch. Unless otherwise noted, the data presented in this Chapter will be presumed to be "dry catch" only.

Particulate Emission Quantities

A 1970 study[4] compiled particulate emission data from various locations downstream of the furnaces at fifty (50) different incinerators which had no air pollution control devices. Figure 47 is a histogram of these data which show the wide variation that exists between incinerators, and even for the same incinerator. A median value of 12 kilograms of particulate emissions per metric ton of refuse (24 lbs/short ton) was determined. This compares

Table 56

TYPICAL PARTICULATE CONTROL REGULATIONS FOR INCINERATORS

Regulating Body	Definition of "Particulate"	Test Procedure	Remarks
U.S. Environmental Protection Agency[15]	Any finely divided liquid or solid material, other than uncombined water, as measured by Method 5	U.S. EPA Method 5	Regulates all matter which is collected on a filter at $\geq$121.1 C (250 F)
N.J. Department of Environmental Protection[2]	Any material, except uncombined water, which exists in a finely divided form as liquid particles or solid particles at standard conditions [21.1 C(70 F), 1 atmosphere absolute pressure]	None specified	Regulates all matter which is particulate at $\geq$21.1 C (70 F)
County of Los Angeles Air Pollution Control District	Any material, except uncombined water, which exists in a finely divided form as a liquid or solid at standard conditions [15.6 C (60 F), one atmosphere absolute pressure]	None specified	Regulates all matter which is particulate at $\geq$15.6 C (60 F)
Virginia State Air Pollution Control Board	Any material, except water in uncombined form, that is airborne and exists as a liquid or a solid at standard conditions [21.1 C (70 F), one atmosphere absolute pressure]	ASME PTC-27* or IIAT-6+	Regulates all matter which is particulate at 21.1 C (70 F), but tests for that which is particulate at stack temperature.

* American Society of Mechanical Engineers Power Test Code 27

+ Incinerator Institute of America Bulletin T-6, "Incinerator Testing"

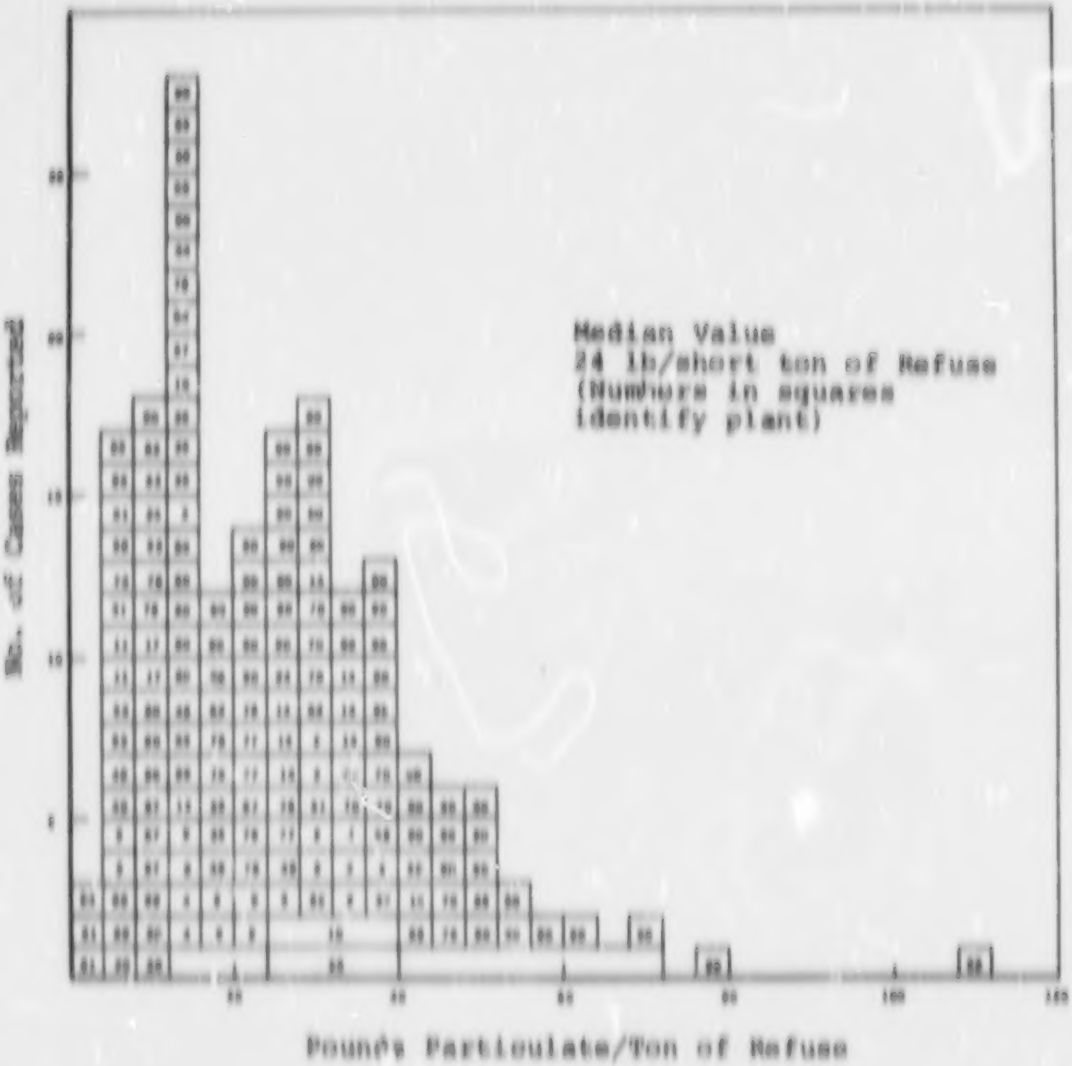

FIGURE 47. HISTOGRAM OF PARTICULATE FURNACE EMISSION FACTORS FOR MUNICIPAL INCINERATORS (CAPACITY: > 50 TON/DAY)

reasonably well with median values of 8.5, 17.5, 10, and 11.3 kilograms per metric ton reported by others.[5-9] A detailed study of a modern waterwall steam generating incinerator showed similar emissions upstream of the pollution control device (Table 57).

Often, regulations are written to limit particulate emission concentrations to a specified value based on operating the incinerator with an amount of air which will result in a carbon dioxide content of 12 percent by volume in the flue gas (excluding the contribution of auxiliary fuel), when measured on a moisture free basis. Therefore, the Table 57 data are represented in other forms in Table 58. Reference 4 contains factors for conversion to additional forms. It should be noted that many regulations define "normal" or "standard" differently from historical usages. Therefore careful reading of definitions is essential.

Uncontrolled particulate emissions vary, depending on the construction and operation of the equipment, as well as the nature of the waste. Some of the major variables are:

- ash content of the solid waste
- underfire and overfire air flows
- burning rate
- furnace temperature
- grate agitation
- combustion chamber design

Three mechanisms are believed to be mainly responsible for particulate emissions:

- mechanical entrainment of particles from the burning waste bed
- the cracking of pyrolysis gases
- the vaporization of metal salts or oxides

An extensive and detailed discussion of these variables and mechanisms are presented in Reference 4. It should be noted that while the particulate emissions from a waterwall furnace may be similar to that from a conventional furnace on a per ton of refuse basis, waterwall emissions may be significantly higher on a concentration basis, due to lower air flows (See Chapter X).

Characteristics of Particulates

The composition of particulate emissions from incinerator furnaces is dependent on design and operation, as well as on the refuse ash composition. A poorly designed or operated incinerator may emit carbon particles (usually referred to as soot), and the inorganic (mineral) type ash will contain a significant quantity of combustibles. Data from six incinerators[4] showed a range of 6 to 40 percent in the combustible content of the furnace particulate emissions. Inorganic contents are shown in Table 59.

Table 57

PARTICULATE EMISSIONS FROM THE FURNACE OF A MODERN WATERWALL INCINERATOR[10]

Refuse Charging Rate, short tons/hr	16.6	16.6	16.7	16.7
Volume percent CO_2 in Flue Gas (Dry Basis)	10.0	10.0	10.1	9.5
Dry catch particulates, lb/hr	388	379	427	398
Wet catch particulates, lb/hr	30	18	30	13
Total particulates, lb/hr	418	397	457	411
Dry catch particulates, lb/short ton	23.4	22.8	25.6	23.8
Wet catch particulates, lb/short ton	1.8	1.1	1.8	0.8
Total particulates, lb/short ton	25.2	23.9	27.4	24.6
Total particulates, lb/metric ton	12.6	12.0	13.7	12.3

Table 59

COMPOSITION OF INORGANIC COMPONENTS OF PARTICULATES FROM FURNACES[4]

Component	Computed for Typical Refuse	NYC Incinerators[11]	
		73rd St.	So. Shore
SiO_2	53.0%	46.4%	55.1%
Al_2O_3	6.2	20.2	20.5
Fe_2O_3	2.6	7.1	6.0
CaO	14.8	10.6	7.8
MgO	9.3	2.9	1.9
Na_2O	4.3	3.0	7.0
K_2O	3.5	2.3	*
TiO_2	4.2	3.1	*
SO_3	0.1	2.7	2.3
P_2O_5	1.5	*	*
ZnO	0.4	*	*
BaO	0.1	*	*
	100.0%		

Particle size distribution and specific gravity of particulate matter are properties which are essential design data for most particulate removal devices. The smaller and/or finer particles require more sophisticated (and expensive) equipment to meet a specific emission limit. Table 60 presents data for three conventional incinerator furnaces. Due to less efficient particle collection testing methods used in the past, it is possible these data are in error in that a portion of the fine particles were not included.

Figure 48 presents additional particle size distribution data. Size distribution, like loading, varies widely. Most factors which affect particle loading also affect the size of particles emitted. Improved incinerator performance which reduces quantities emitted, normally decreases the size of the individual particles. The particulate matter is always quite heterogeneous, consisting of flyash, with properties such as shown in Tables 59 and 60, combined with large, low density flakes. Particle density typically ranges from 2 to 3 g/cc.

Electrical resistivity is an important property of particulates necessary for design of electrostatic precipitators, commonly used in modern incinerators. High resistivity reduces collection efficiency, while low resistivity may result in re-entrainment of the particle into the gas stream after collection. Resistivity is a function of the basic particle characteristics, and composition and temperature of the flue gas stream. The presence of moisture and very low concentrations of certain chemical compounds, such as sulfur trioxide and ammonia, in the flue gas may strongly influence particle resistivity and precipitator efficiency. Figure 49 shows the particle electrical resistivity for emissions from three furnaces. The desirable range of resistivity, 10^4 to 10^{10} ohm-cm, influences the choice of electrostatic precipitator operating temperature.

Target Particulate Emission Levels

Allowable particulate emissions are determined by three standards, usually concurrently:

. Air quality in the regions affected by the thermal processing facility
. Concentration or rate of emissions from the thermal processing facility
. Visual appearance of the emissions from the thermal processing facility

These standards exist on the Federal level for new facilities (construction commenced after 12/23/71),[18] and on the State level for existing facilities as well.

Federal (and many State) requirements for air quality are set at two levels, as shown in Table 61, a primary standard which is designed to protect public health, and a secondary standard which is designed to protect public welfare (e.g., animal or plant life, or property, or enjoyment thereof). For purposes of air quality standards, "particulate" generally means that which is filterable from the air and which remains on the filter after conditioning at 15 to 35 C (59 to 95 F).

Table 60
PROPERTIES OF PARTICULATES LEAVING FURNACES[17]

	Installation		
Physical Analysis	1 (250 TPD)	2 (250 TPD)	3 (120 TPD)
Specific gravity, g/cc	2.65	2.70	3.77
Bulk density g/cc (lb/CF)	-	0.496(30.9)	0.151(9.4)
Loss on ignition at 750 C, wt. percent	16.5	6.15	33.4
Size distribution (percent by weight)			
< 2 microns	13.5	14.6	23.6
< 4 microns	16.0	19.2	30.0
< 6 microns	19.0	22.3	33.7
< 8 microns	21.0	24.8	36.3
<10 microns	23.0	26.8	38.1
<15 microns	25.0	31.1	42.1
<20 microns	27.5	34.8	45.0
<30 microns	30.0	40.4	50.0
Particulate emission rate, kilograms/MT (lb/ST)	6.1 (12.1)	12.3 (24.6)	4.6 (9.1)

TPD = short tons per day
MT = metric ton
ST = short ton

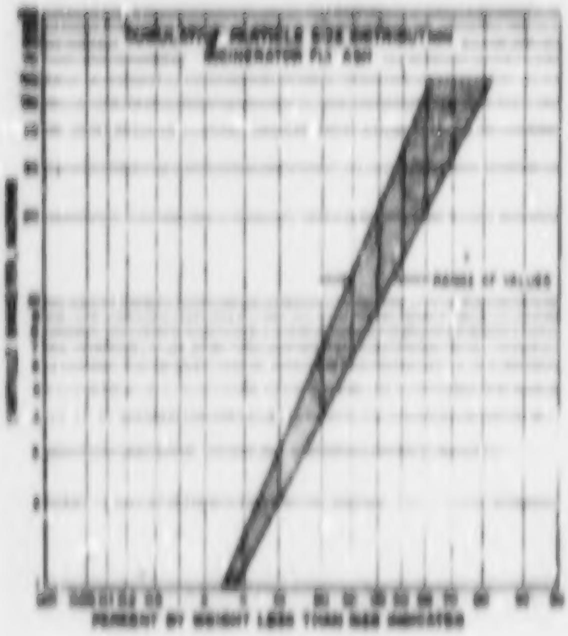

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FIGURE 46. INCINERATOR FLYASH PARTICLE SIZE DISTRIBUTION*

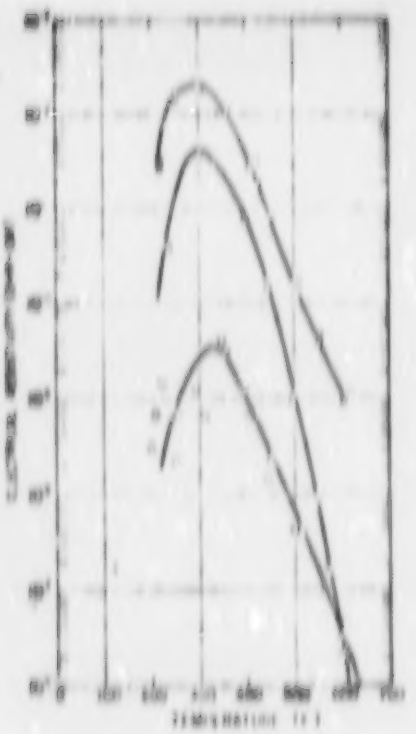


FIGURE 49. BULK ELECTRICAL RESISTIVITY OF ENTRAINED PARTICULATES LEAVING THREE LARGE, CONTINUOUS FEED FURNACES AT 6 PERCENT WATER VAPOR.[17]

Table 61

NATIONAL AMBIENT AIR QUALITY STANDARDS[14]

National Primary Ambient Air Quality Standards for Particulate Matter	National Secondary Ambient Air Quality Standards for Particulate Matter
The national primary ambient air quality standards for particulate matter, measured by the reference method described in the regulation,* or by an equivalent method, are:	The national secondary ambient air quality standards for particulate matter, measured by the reference method described in the regulation,* or by an equivalent method are:
(a) 75 micrograms per cubic meter--annual geometric mean.	(a) 60 micrograms per cubic meter--annual geometric mean, as a guide to be used in assessing implementation plans to achieve the 24-hour standard.
(b) 260 micrograms per cubic meter--maximum 24-hour concentration not to be exceeded once per year.	(b) 150 micrograms per cubic meter--maximum 24-hour concentration not to be exceeded more than once per year.

* High volume sampling method described in Appendix B of reference 14.

With the sophisticated computer modeling techniques now available, the air quality in regions affected by a thermal processing facility can be reasonably predicted for varying stack emission rates and meteorological conditions (e.g., wind speed and direction, vertical temperature profiles, humidity, etc.), taking into account stack height and exit velocities, land topography, already existing particulate concentrations, and other sources of particulates. While not specific to thermal processing facilities, the air quality standards nevertheless must not be exceeded because of insufficient control in new and existing installations.

For thermal processing facilities which commenced construction after December 23, 1971, and which charge more than 1.89 metric tons per hour (50 short tons/day) of solid waste,* the very specific Federal Regulation for particulate emission concentrations must be met.[15] These standards prohibit the discharge into the atmosphere of particulate matter, the concentration of which is in excess of 0.18 grams per cubic meter (@ 21.1 C, one atmosphere) which is equal to 0.08 grains/standard cubic foot (21.1 C, one atmosphere) of flue gas on a dry basis corrected to 12 percent carbon dioxide by volume, maximum 2-hour average. The particulate emissions are to be measured in accordance with U.S. Environmental Protection Agency "Method 5, Determination of Particulate Emissions from Stationary Sources,"[15] which measures only "dry catch" particulates. A requirement for recording burning rates, hours of operation, and any particulate emission measurements which are made is also included.

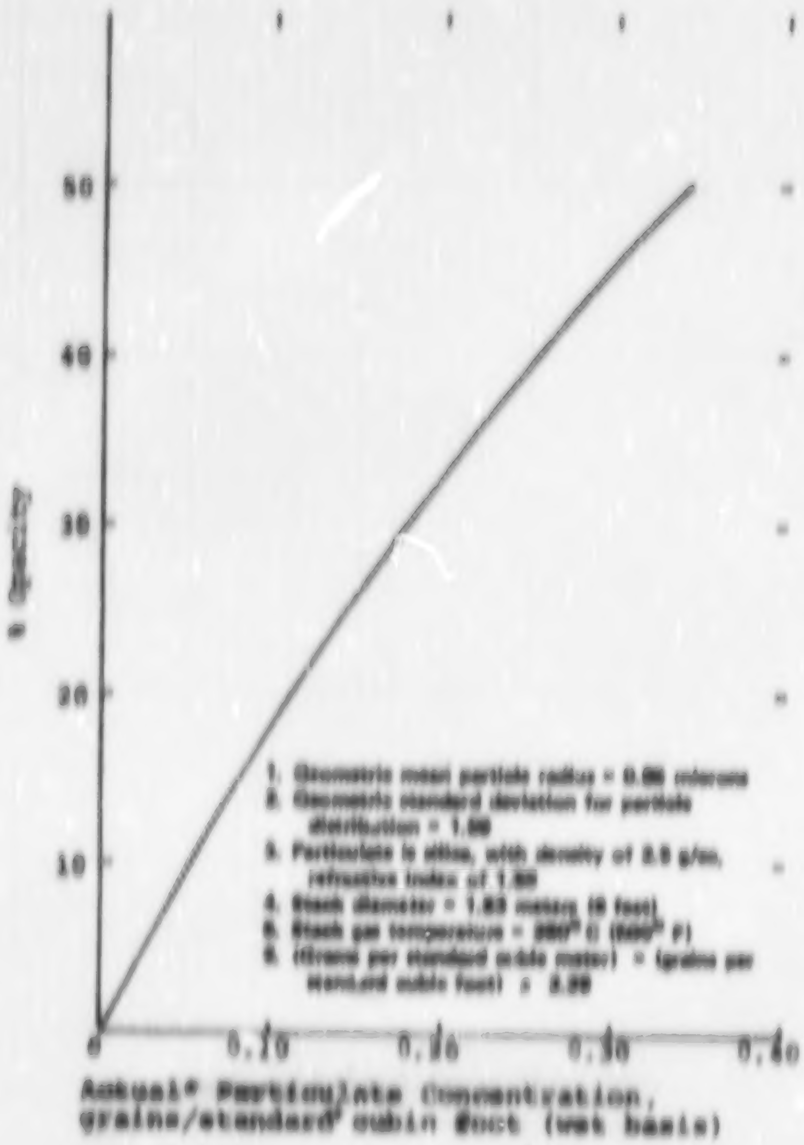
It was originally proposed that the Federal emission standards for incinerators and other sources would be for total particulates, which included dry catch and wet catch. As can be deduced from Table 57 and 58, for incinerators the wet catch corresponds to a quantity on the same order of magnitude as the emission standard. As will be seen in the control section, the wet catch portion of the particulates are not efficiently collected by some devices and in themselves could cause noncompliance, if this proposed standard were ever promulgated.

On the State level, similar regulations exist for both new and existing facilities, but the actual numerical standard, the definition of "particulate," and the test method may be significantly different. State regulations may also have prohibitions against particulate emissions which are visible. These regulations may set a specific standard such as a limit on opacity** (typically 20 percent), or an equivalent smoke density (e.g., Ringelmann No. 1), or simple prohibition of any visible particles.[9]

Actual data correlating particulate concentration with the resulting opacity or smoke density have not been found, but a correlation is presented in Figure 50 using a method[18] which takes into account particulate concentration, refractive index, geometric mean radius (and standard deviation), density, stack diameter, and gas temperature. The claim that 0.09 grams per standard cubic meter (0.04 grains/standard cubic foot) results in a clear stack[16] is not inconsistent with this correlation.

* Defined as refuse, more than 50 percent of which is municipal type waste.[15]

** The degree of obstruction to the transmission of light.



*Not corrected to 12% CO₂ / + 21.1°C, 1 atmosphere

FIGURE 80. ESTIMATED CORRELATION BETWEEN OPACITY AND PARTICULATE CONCENTRATION FOR AIR POLLUTION CONTROLLED INCINERATORS

Particulate Emissions Control

Even a modern well-designed and operated incinerator cannot meet Federal and most, if not all, State regulations for particulate emissions without an air pollution control system. Comparing data from Table 58 with Federal emission requirements (Table 62), it is apparent that efficiencies in excess of 93 percent on a weight basis are required. Visual requirements, by State or local agencies, of less than 20 percent opacity may increase this efficiency requirement even further.

Mass particulate emission standards are corrected to 12 volume percent CO_2 excluding the contribution of auxiliary fuel (or some other measure of excess air), which effectively limits the emission to a fixed amount per ton of solid waste fired. Thus, air dilution in a refractory incinerator, which may use twice as much air as a waterwall incinerator, is not an aid in meeting emission limits. However, because opacity is an absolute standard, the refractory incinerator may in fact be aided by normal dilution in meeting an opacity requirement. It may also be aided by decreasing the size of a single stack, e.g. by using four stacks with four incineration trains instead of one or two stacks, because of the effect of stack size on opacity measurements.

Considering the particle size data presented in Figure 40, it is apparent that to achieve a minimum of 90 percent efficiency, all the particles larger than 1 to 3 microns (one-millionth of a meter) must be removed. This requirement effectively eliminates the simple air pollution control systems traditionally used on incinerators, although it may sometimes be advantageous to use one of these simpler devices as a first stage collector, for example, to reduce the required efficiency of the final collector. Numerous discussions of these systems, which include settling chambers, wetted baffle spray systems, cyclones, and low energy scrubbers are available.[8,19,23] Therefore, they will not be considered further in this publication.

Electrostatic precipitators, fabric filters, and certain types of scrubbers appear to be the only commercially available devices which have the capability to meet the current emission standards for municipal incinerators. Newer forms of these devices, including charged droplet scrubbers and high velocity wet precipitators, may have advantages over more conventional devices but these have not been commercially demonstrated for incinerator applications.

Electrostatic Precipitators

Electrostatic precipitators have been used in utility and industrial steam generating boilers and many other applications for over fifty years, with a relatively good performance record. Not until 1967 were these devices applied to municipal incinerators in the United States, although there are probably more than forty installations in Europe and Japan. Almost all new thermal processing facilities built since 1969, however, have utilized electrostatic precipitators for particulate emission control (Table 61).

Table 62

PARTICULATE EMISSION DATA FROM UNCONTROLLED WATERWALL INCINERATOR COMPARED WITH FEDERAL STANDARDS

Particulate Emission Concentration	Uncontrolled Incinerator*	Federal Standard or Equivalent	Percent Reduction Required
Grains/SCF (dry)**	1.18	0.08	93.3
Grams/SCM (dry)++	2.70	0.18	

* Derived from Tables 57, 58; Average of four tests. Corrected to 12 percent CO_2 by volume, dry basis; "dry catch" only.

** Standard (70 F, 29.92"Hg) cubic feet, dry basis

++ Standard (70 F, 29.92"Hg) cubic meters, dry basis

70 F = 21.1 C
29.92"Hg = 1 atmosphere

Table 63

PARTIAL LISTING OF ELECTROSTATIC PRECIPITATOR INSTALLATIONS AT THERMAL PROCESSING FACILITIES IN THE UNITED STATES AND CANADA, INCLUDING DESIGN PARAMETERS*

Plant	Capacity TPD	Furnace Type	Gas Flow ACFM	Gas Temp F	Gas Velocity FPS	Residence Time Sec.	Plate Area ACFM/ft²	Power Input KVA	Pressure Drop "H_2O gage	Efficiency wt. %
Montreal	4 x 320	WW	112,000	536	3.5	3.3	6.2	35	0.5	95.0
Stamford	1 x 220	Special R	160,000	600	6.0	3.3	6.6	57	0.5	96.0
Stamford	1 x 360	R	225,000	600	3.6	5.0	4.5	225	0.5	95.0
Stamford	1 x 150	R	75,000	600	3.7	4.9	4.6	75	0.5	95.0
SW Brooklyn	1 x 250	R	131,000	580	4.4	3.2	6.7	47	2.5	94.3
So. Shore, N.Y.	1 x 250	R	136,000	600	5.5	3.3	5.8	33	0.5	95.0
Dade City, Fla.	1 x 300	R	286,000	570	3.9	4.0	5.7	48	0.4	95.6
Chicago, NW	4 x 400	WW	110,000	450	2.9	4.6	5.5	40	0.2	96.8
Braintree, Mass.	2 x 120	WW	32,000	600	3.1	4.5	5.5	19	0.4	93.6
Hamilton, Ont.	2 x 300	WW	81,000	585	3.5	5.4	3.9	70	0.5	98.5
Washington, D.C.	6 x 250	R	130,000	550	4.1	3.9	4.9	77	0.4	95.0
Eastman Kodak	1 x 300	WW	101,500	625	3.4	5.5	3.8	106	—	97.5
Harrisburg, Pa.	2 x 360	WW	100,000	410	3.5	5.1	5.0	40	0.2	96.8

R = refractory lined WW = waterwall
* Most of data from reference 20

NOTE: Except for capacity, DATA refer to design parameters for one precipitator; several may exist

In an electrostatic precipitator, a high, normally negative, voltage gradient is impressed across a pair of electrodes producing a corona discharge (the visible sign of ionization of gas molecules) at the negative electrode. Most of the ions produced are negatively charged. As the ions migrate toward the grounded (relatively positive) electrode, they collide with entrained particles, charging these particles negatively. The negatively charged particles in turn move toward the grounded electrode where they are attached and held by a combination of electrical, adhesive, and cohesive forces while their negative charge is gradually conducted through the layers of previously collected dust to the grounded electrode. The resistance to conduction is termed "dust resistivity."

Too high a resistivity results in a high voltage drop across the dust layer, reducing particle collection because of depressed electrical fields in the precipitation zones and lower levels of particle charge.[21] In extreme cases, very high resistivity may result in "back corona," generating positive ions which tend to neutralize the electrical field and upset particle collection. Resistivity, which is a complex function of both gas and particle characteristics, is a primary parameter to be considered in precipitator design.

The major elements of a commercial electrostatic precipitator are the high voltage power supply and controls, discharge (corona) electrodes, collecting (grounded) electrodes, rappers to dislodge agglomerated dust from electrode surfaces, a gas-tight shell to contain the precipitation zone, hoppers below the precipitation zone to receive dislodged dust, and gas inlet and discharge zones designed to distribute the gas uniformly across the precipitation zone. A typical configuration is shown in Figure 51.

High Voltage Power Supply and Controls. The high voltage system is designed to provide high voltage direct current to the discharge electrodes. The system consists of:

1. Typically 460 volt, 60 Hz, single phase alternating current power supply.

2. An electrical control circuit incorporating either a saturable reactor, or an SCR (silicon-controlled rectifier).

3. A transformer-rectifier set (encased in an oil tank) to increase the voltage to the desired value in the range of 30,000 to 80,000 volts, and to convert alternating to direct current. Silicon diode rectifiers have replaced earlier mechanical, vacuum tube, and selenium types.

Automatic control systems and electrical sectioning of precipitators, although increasing initial cost somewhat, are important in maintaining maximum precipitator performance.[17] Proper design and placement of high voltage insulators is necessary to overcome failures due to dirt and moisture.

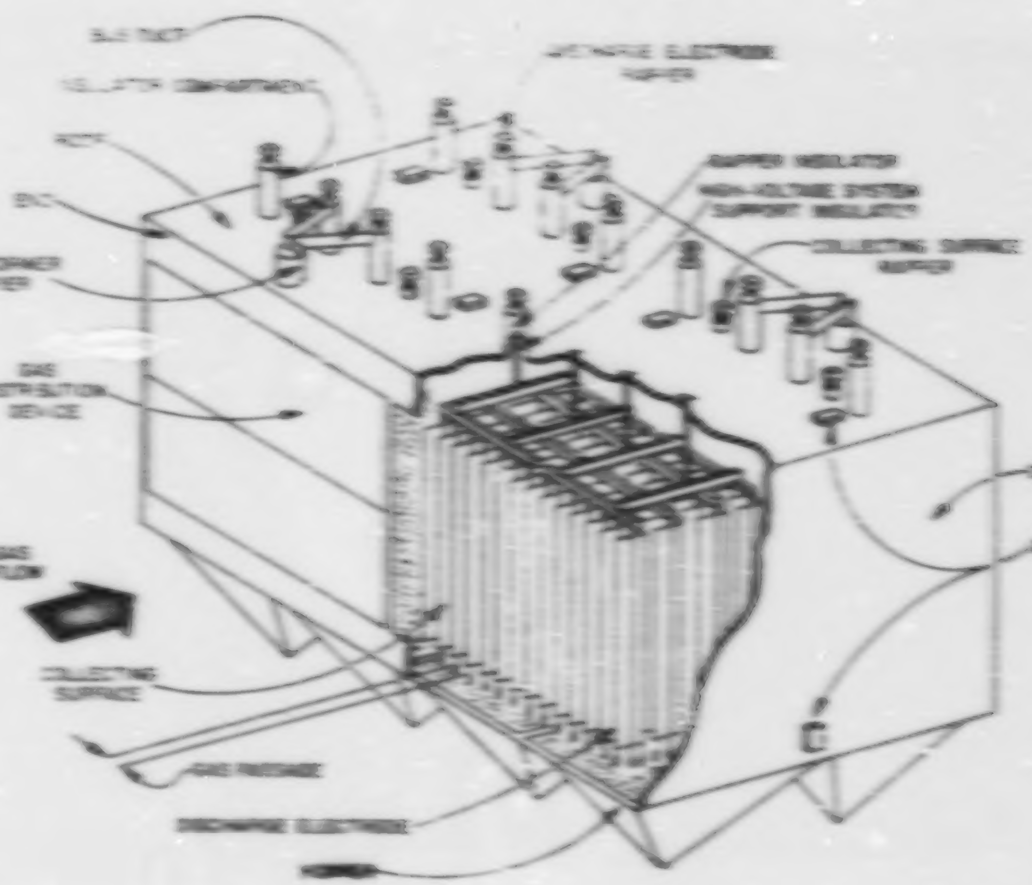

BUS DUCT
INSULATOR COMPARTMENT
ROOF
TRANSFORMER RECTIFIER
GAS DISTRIBUTION DEVICE
GAS FLOW
COLLECTING SURFACE
GAS PASSAGE
DISCHARGE ELECTRODE
HOPPER
DISCHARGE ELECTRODE RAPPER
RAPPER INSULATOR
HIGH-VOLTAGE SYSTEM SUPPORT INSULATOR
COLLECTING SURFACE RAPPER

FIGURE 51. TYPICAL ELECTROSTATIC PRECIPITATOR

Discharge Electrodes. The discharge electrodes, which take the form of rods or wires with or without superimposed sharp points or edges to enhance the corona effect, hang precisely along the center lines of the gas passages between the collection electrodes. The discharge electrodes must be designed with great care to maintain uniform spacing and to minimize fatigue. These may be the suspended wire type with weights, as shown in Figure 61, or the electrodes may be mounted in stiff frames. Each electrical section, containing a multitude of discharge electrodes, is electrically isolated from the remainder of the precipitator.

Collection Electrodes. For incinerator applications, these are parallel steel plates carefully spaced at a predetermined value in the range of 20 to 30 centimeters (8 to 12 inches) apart, depending on the voltage used. The plates may be smooth, but are normally corrugated or equipped with fins or carefully designed baffles to increase strength and to provide quiescent zones, avoiding particle re-entrainment while maintaining smooth gas flow.

Rappers. Rappers or vibrators are used during precipitator operation to shear the collected dust layers away from the collecting electrode. Both intensity and time may be controlled to induce shearing off relatively large agglomerates, avoiding particle re-entrainment. Such losses are also minimized by sequential rapping of shock-isolated rapping sections in series, so that an opportunity exists to recapture particles which are re-entrained in the inlet sections. A variety of rapping mechanisms and locations are used, including mechanical, electromagnetic, and pneumatic devices, top or end mounted. A group of mechanically driven free-swinging hammers on a single shaft, each hammer rapping the end of single plate, is one simple arrangement, but one in which intensity is not readily controlled. Similar rapping arrangements are adapted for use on groups of discharge (negative) electrodes because some dust almost inevitably clings to these, due to impaction and positive ion formation.

Flyash Removal. The hoppers may be discharged periodically through slide valves or continuously through rotary valves or feeders to a flyash removal system. The removal system is usually dry, using screw or drag conveyers, or vacuum or pneumatic transport. However, slurry systems can be used.

Proper hopper design and dumping procedures are vital, since buildup of flyash can short out electrodes causing precipitator damage. Level detectors are useful, and automatic timing devices should be used where periodic dumping is practiced.

Gas Inlet and Discharge Zones. Uniform flow into and through the precipitator must be maintained to insure adequate performance. The reduction in gas velocity from the usual practice of about 10 to 20 meters per second (33 to 66 ft/sec) in inlet ducts to about 0.9 to 1.8 meters per second (3 to 6 ft/sec) in the precipitator, changes in gas direction, and the necessity for limiting the amount of total ductwork pose difficult design problems with regard to obtaining uniform flow. Careful design of splitters or vanes and incorporation of perforated plates at the precipitator inlet will improve gas distribution. Test models scaled 1 to 16 are sometimes used to aid in design work. Flow distribution tests should be included in performance evaluation for new or rebuilt precipitators.

Gas distribution through the precipitator is affected too by the gas outlet design, also deserving of careful attention. Another serious problem can be created by gas bypassing below the collecting plates through the hopper area. This condition can usually be improved by the use of baffles.

Precipitator Sizing. The design of electrostatic precipitators is based on knowledge of gas and solid physical and chemical properties, particle inlet loadings, gas rate, required efficiency, and also on familiarity with the idiosyncracies of the particular application. For example, for incinerator operation, the design should reflect knowledge of the expected temperature range, the frequency of shutdown, variability in flyash composition and properties, geographical location, and other variables. Using both theoretical and empirical design consideration, and considering cost optimization, the designer will specify major parameters, usually in the ranges shown in Table 64.

Although the required mass particle removal efficiency, based on Federal emission standards previously discussed, may be less than 96 percent, opacity requirements approaching a "clear stack" may bring design efficiency to 99 percent (or even higher), depending on uncontrolled loading, particle size, condensibles present, stack diameter, and other factors. High design efficiencies require extraordinary attention to all design and construction details to insure continuing high efficiency performance. It should be emphasized that the mechanical and electrical designs, some important aspects of which have been discussed here, are as important to adequate electrostatic precipitator performance as the basic size parameters. Electrostatic precipitator installations both in the United States and elsewhere have shown that, with careful design and operation, efficiency requirements for "dry catch" particulates can be met. Actual performance data for an electrostatic precipitator operating on the effluent from a waterwall incinerator are provided in Table 65.

Corrosion due to acidic components of the flue gas, such as hydrogen chloride, can be a problem in precipitator operation. The gas temperature following heat and/or quench facilities must be sufficiently high to avoid acid condensation on cold surfaces. Hot air purging and preheat burners can minimize acid gas contact with cold surfaces during shutdown and startup. Sufficient insulation of all metal surface exposed to outdoor conditions is especially important. Hopper heaters are useful, both to avoid corrosion and to avoid bridging problems due to even minor amounts of moisture deposition on flyash.

Scrubbers

Devices that contact incinerator flue gas with water have traditionally been used both to clean the gases and to cool them for protection of duct, stack, and fan materials. These devices, which usually consisted of little more than a large spray chamber with baffles, are inadequate to meet modern

Table 64

TYPICAL ELECTROSTATIC PRECIPITATOR DESIGN PARAMETERS FOR INCINERATOR APPLICATIONS

Plate Spacing	20-30 cm (8-12 in)
Velocity Thru Precipitator	0.9-1.8 meters/sec (3-6 ft/sec)
Vertical Height of Plates	3.6-12 meters (12-40 ft)
Horizontal Length of Plates*	0.5-1.5 x Height
Applied Voltage	30,000-60,000 volts
Gas Temperature	177-343 C (350-650 F)
Gas Residence Time in Precipitator	3-6 seconds
Draft Loss	3-20 mm water (0.1-0.8 in)
Fields (electrical stages) in Direction of Gas Flow	1-4
Total Power for Precipitator	7-35 kW per m³/min. (0.2-1 kW/1000 ACFM)
Collection Area	400-1000 m² per 1000 m³/min (122-305 ft²/1000 ACFM)
Efficiency	95-99%
Gas Flow per Precipitator	850-8500 m³/min (30,000-300,000 ACFM)
Migration Velocity**	6-12 cm/sec (0.2-0.4 ft/sec)

* Aspect ratio = (total horizontal length (depth) of collection plates) ÷ (height of collection plates) = 0.5-1.5

** Mean average effective migration velocity of a particle toward the collection electrode. Sometimes called precipitation rate or drift velocity.

Table 65

PERFORMANCE DATA FROM ELECTROSTATIC PRECIPITATOR ON WATERWALL FURNACE[10]

Refuse Charging Rate				
Short tons/hr	16.6	16.6	16.7	16.7
Dry Gas Composition (by volume)				
% CO_2	10.0	10.0	9.9	9.1
% O_2	9.4	9.4	7.4	8.5
Excess Air, %	78	78	87	98
Inlet Measurements				
Flow rate, SCFM (dry)	46,500	42,100	51,900	51,500
Temperature, F	338	307	400	415
Water Content, % by volume	11.0	10.8	13.9	12.7
Particulates--dry catch				
grains/SCF (dry) corrected*	1.17	1.26	1.14	1.14
grains/SCF (dry) actual	.975	1.05	.941	.865
Particulates--wet catch				
grains/SCF (dry) corrected*	.090	.060	.079	.036
grains/SCF (dry) actual	.075	.050	.065	.027
Particulates--total				
grains/SCF (dry) corrected*	1.260	1.320	1.219	1.176
grains/SCF (dry) actual	1.050	1.100	1.006	0.892
Outlet Measurements				
Flow rate SCFM (dry)	43,600	43,400	51,900	51,500
Temperature, F	352	356	393	398
Water Content, % volume	9.7	8.5	13.9	12.7
Particulates--dry catch				
grains/SCF (dry) corrected*	.0331	.0283	.0400	.0270
grains/SCF (dry) actual	.0276	.0236	.0330	.0205
Particulates--wet catch				
grains/SCF (dry) corrected*	.0103	.0134	.0090	.0130
grains/SCF (dry) actual	.0086	.0112	.0074	.0099
Particulates--total				
grains/SCF (dry) corrected*	.0434	.0417	.0490	.0400
grains/SCF (dry) actual	.0362	.0348	.0404	.0304
Efficiency				
% Removal--dry catch	97.17	97.75	96.49	97.63
% Removal--wet catch	88.56	77.67	88.61	63.89
% Removal--total	96.56	96.84	95.98	96.60

* Corrected to 12 percent CO_2

emission control requirements, though similar devices can still be used where flue gas cooling is required. As noted earlier, in order to meet most recent particulate emission regulations, it is necessary to install devices which efficiently remove particles in the 1 to 5 micron size range. This can be accomplished by some forms of a more sophisticated family of gas/water contacting devices known as scrubbers, or sometimes as wet or water scrubbers.

Various techniques are used in scrubbing, but all rely on "wetting" the particle with water in order to enlarge them, allowing for easier removal from the gas stream. The efficiency of a particular type of scrubber on a given particle size can be related to the energy used to force the gas through the collector and to generate the water sprays. This energy may be supplied with fans as pressure to the gas stream (gas motivated), with pumps as pressure to the water stream (liquid motivated), or mechanically. The latter has not found commercial usage, but the former methods are widely used.

Gas motivated scrubbers are referred to as venturi or orifice types. Liquid motivated scrubbers are referred to as jet venturi or ejector types, or impact scrubbers. The energy required in either case represents a very significant incinerator operating cost, especially when electrical power is used to drive fan or pump motors.

Research and development work is underway to improve the performance of scrubbers and to reduce energy requirements.[24] Various commercial claims are made that such energy reductions are already possible. While this may be so, it is beyond the scope of this publication to assess such developments which have not been demonstrated for thermal processing applications. However, any scrubber proven capable of performing equivalently to those described herein with lower energy consumption merits special consideration, because of the very significant contribution of scrubber energy losses to incinerator utility costs.

In the venturi-type scrubber, the gases are passed through a restricted "throat", where water is injected and the gas velocity accelerated, typically to 60 to 122 meters per second (200 to 400 ft/sec), promoting intimate gas-liquid contacting, with gas pressure drops up to 122 mm Hg (60 in. H_2O) and higher. The wetted particles are then collected in a mechanical type device, such as cyclonic separation chamber and/or wire screen demisters. Water rates are in the range of 0.7 to 5.3 CM/1000 CM per minute (5 to 40 GPM/1000 CFM) of gas at the scrubber outlet (Table 66). Variations of the venturi or orifice gas motivated scrubbers may be found in Figures 52, 53, and 54.

Energy for a venturi scrubber is supplied by fans upstream or downstream of the scrubber. The power requirement is about four (4) kilowatts per 1000 cubic meters/minute per mm Hg pressure drop (about 0.25 horsepower per 1000 cubic feet per minute per inch water pressure drop). Location of the fan is significant. A downstream fan must contend with increased mass flow due to water evaporation into the gas stream, although the volumetric flow rate may be lower because of the lower temperature. A downstream fan must also contend with impingement of sometimes corrosive water droplets, carried over from the scrubber or from condensation; while an upstream fan must contend with the design and maintenance problems associated with operation on a dirty gas at elevated temperatures. The downstream option is normally chosen for incinerator type systems.

Table 66

TYPICAL VENTURI SCRUBBER OPERATING PARAMETERS

Throat Gas Velocity		Water Rate*		Pressure Drop	
m/sec	ft/sec	l/1000 l	GPM/1000 CFM	mm Hg	in. H_2O
18-38	60-125	2.0 - 5.3	15-40	3.7-37	2-20
30-84	100-275	1.1 - 2.7	8-20	15-75	8-40
61-122+	200-400+	0.7 - 2.0	5-15	28-149+	15-80+

* Total water rate per unit rate of water saturated gas. Usually, the major portion of the water requirement is supplied by recycled water.

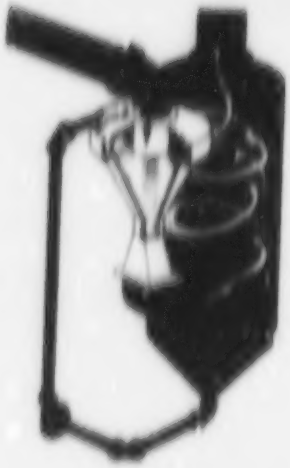


FIGURE 52. GAS MOTIVATED VENTURI SCRUBBER VARIATION (COURTESY OF CHEMICO)

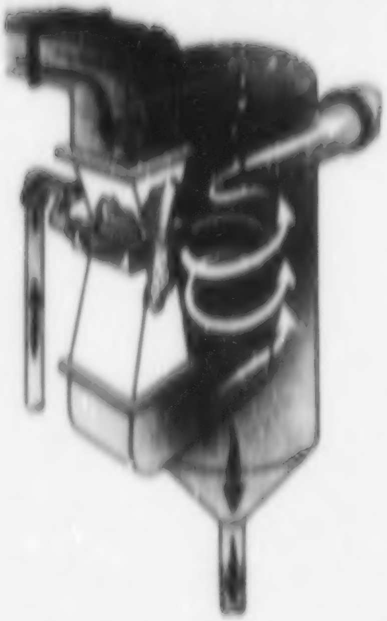


FIGURE 53. GAS MOTIVATED VENTURI SCRUBBER VARIATION
(COURTESY OF CHEMICO)

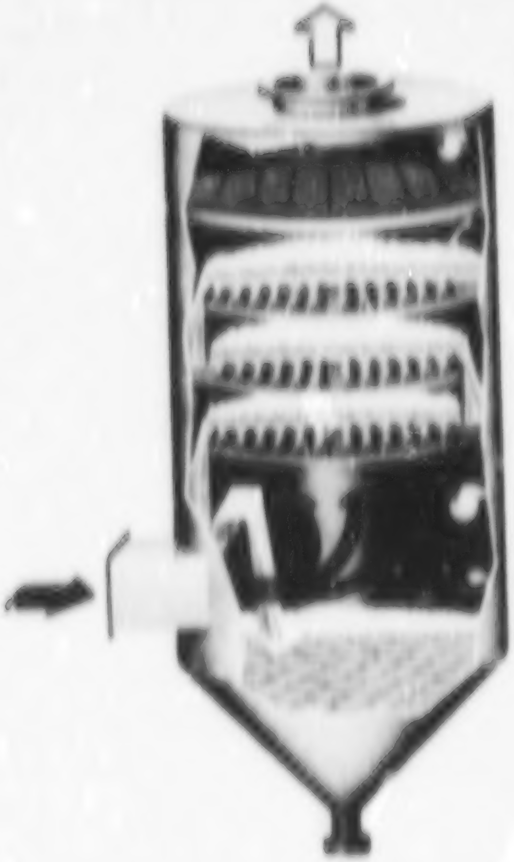


FIGURE 54. GAS MOTIVATED ORIFICE TYPE SCRUBBER
(COURTESY OF KOCH ENGINEERING)

In an ejector type venturi, high pressure liquid pumps rather than fans supply the motive power. As shown in Figure 55, water is supplied through a high pressure spray nozzle to the venturi section of the scrubber. The gas and particulates are drawn into the scrubber and entrained by the liquid entering the venturi. Compression of the gas in the venturi creates the necessary pressure differential across the scrubber unit.

The gas and liquid droplets are intimately mixed by the turbulence created in the venturi, and the wetted particulates are separated in a section following the venturi, using baffles or other devices.

The total water requirement is usually in the range of about 5.4 cubic meters per 1000 cubic meters of flue gas (about 40 to 50 GPM/1000 CFM), primarily recycled water. Makeup water requirement is determined by the rate of solids removal from the gas. The water pressure required is typically near 5.8 atmospheres absolute (about 70 psig).

Energy requirements are similar to venturi scrubbers, but the need for a fan can be avoided where there are no other large draft requirements in the system. There are no known applications of ejector type venturi scrubbers to incinerators, but the possibility is worth investigating.

Since scrubber water requirements are high, recirculation is usually practiced, both to minimize makeup water and to minimize the amount of wastewater to be treated. The ratio of recycle to makeup water is determined by the quantity of particulates to be removed, by the tolerance of the scrubber design to the concentration of both soluble and insoluble materials in the water, which tend to buildup with increased recycle, and the amount of water evaporated or otherwise lost.

Incinerator stack gases contain acidic gases which are soluble in water. These gases dissolve during scrubbing and cause the water to become acidic. As a result, even stainless steel scrubbers have been known to corrode away. Therefore, pH control by alkali addition must be practiced. This has two other important effects. First, undesirable acidic gases such as hydrogen chloride, hydrogen fluoride, and sulfur oxides are removed to some degree; and second, some carbon dioxide is removed, increasing alkali consumption. The latter may also have an important regulatory effect. Since emission standards are based on a 12 percent carbon dioxide content, the lower carbon dioxide content exiting from a scrubber can require an even lower actual particulate emission rate. The regulations are not clear on this matter.

A prediction of efficiency versus pressure drop (energy input) for a venturi scrubber applied to a municipal incinerator has been made.[4] Figure 56 presents this data assuming an inlet particulate concentration of 1.25 grains per standard cubic foot dry, (2.87 grams per standard cubic meter dry) corrected to 12 percent CO_2. This data predicts that the Federal Standard of 0.08 grains/standard cubic foot (0.18 grams per standard cubic meter) can be reached, if at all, only at very high pressure drop.

However, several venturi scrubbers have been applied to incinerators, operating data for which are also shown on Figure 56. This data does not follow the predicted performance curve, but more nearly approximates the

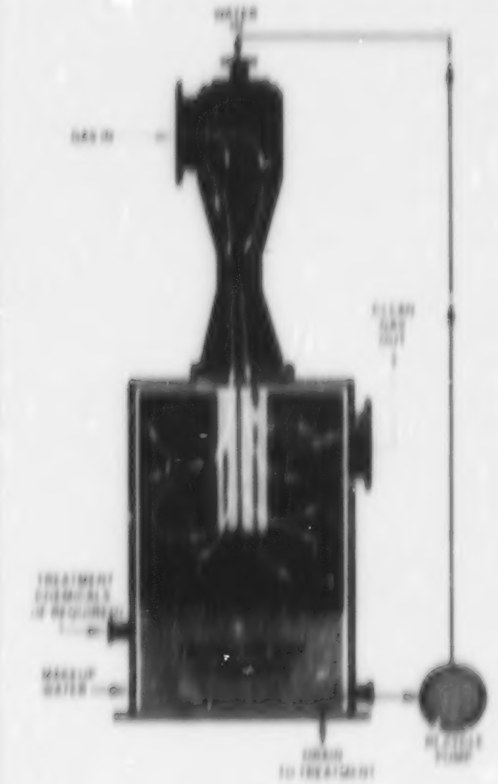
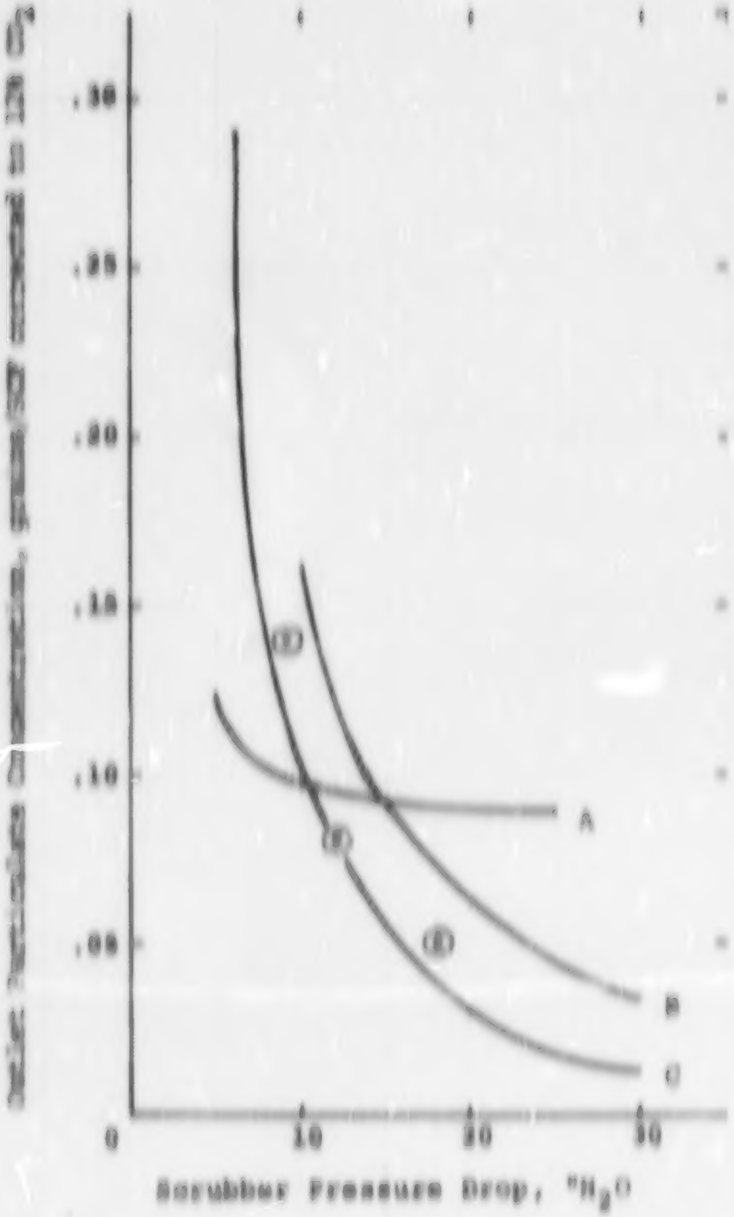

WATER IN
GAS IN
CLEAN GAS OUT
TREATMENT CHEMICALS IF REQUIRED
MAKEUP WATER
DRAIN TO TREATMENT
RECYCLE PUMP

FIGURE 55. LIQUID MOTIVATED JET EJECTOR SCRUBBER (COURTESY OF CROLL-REYNOLDS)



● represents actual data from scrubbers on municipal incinerators

A. represents predicted performance of venturi scrubber on municipal incinerator

B. represents predicted performance of venturi scrubber on fine particles (<5u)

C. represents one manufacturer's claimed performance of venturi scrubber on one micron (1u) particles

Note:

grams/SCM = 2.29 x grains/SCF

mm Hg = 1.87 x "H_2O

FIGURE 55. PERFORMANCE CURVE FOR VENTURI SCRUBBERS

efficiency curve for a one micron particle or "fine particles" (<5μ).[24] It would appear that a pressure drop of at least 22 to 32 mm Hg (12 to 17 in H_2O) is required to achieve the Federal standard. A "clear stack" (e.g., 0.07 g/SCM or 0.03 gr/SCF) may require more than 37 mm Hg (20 in H_2O), although the scrubber water vapor plume tends to reduce this requirement by masking the particulate opacity. The cleaned gases usually leave a scrubber at a temperature near 65.6 C (150 F), saturated with water vapor, thereby virtually always having a visible appearance from condensation of water vapor into fine droplets in the atmosphere. Commonly referred to as a steam or water vapor plume, this phenomena is exempt from opacity regulations, but has other effects which may require control. Steam plume control is discussed elsewhere in this Chapter.

Wastewater from scrubbers can often be used to quench the furnace residue prior to treatment or disposal, thereby reducing both water and treatment costs.

Fabric Filters

Fabric filters or baghouses are widely used in industrial applications, but only a few have been built for refuse incineration in the United States and Europe. In this device, the particulate-bearing gas stream is passed through a fabric filter medium of woven or felted cloth, which traps the particulates and allows the gas to pass through the pores of the fabric. These pores are as large as 100 microns, but even sub micron particles are captured, due to a buildup on the cloth of a fragile porous layer of collected particles which blocks the pores. For various economic and practical reasons, fabric filters are virtually always constructed in tubular form (bags) with numerous bags housed in a steel vessel (baghouse).

In order to operate continuously, the filter must be intermittently cleaned. This is accomplished by various means, including manual, mechanical, or pneumatic shaking. The dislodged particulates fall to a hopper where they are removed by screw or other types of conveyor, as with precipitator hoppers. Figures 57 and 58 depict various baghouse designs.

Design parameters include:

- choice of fabric (based on gas temperature, humidity, and particle characteristics)
- size-length, diameter, and number of bags based on an empirically obtained air flow to cloth ratio, and mechanical considerations.
- method of cleaning (based on particle characteristics and vendor preferences)
- method of precooling the gases to the operating temperature

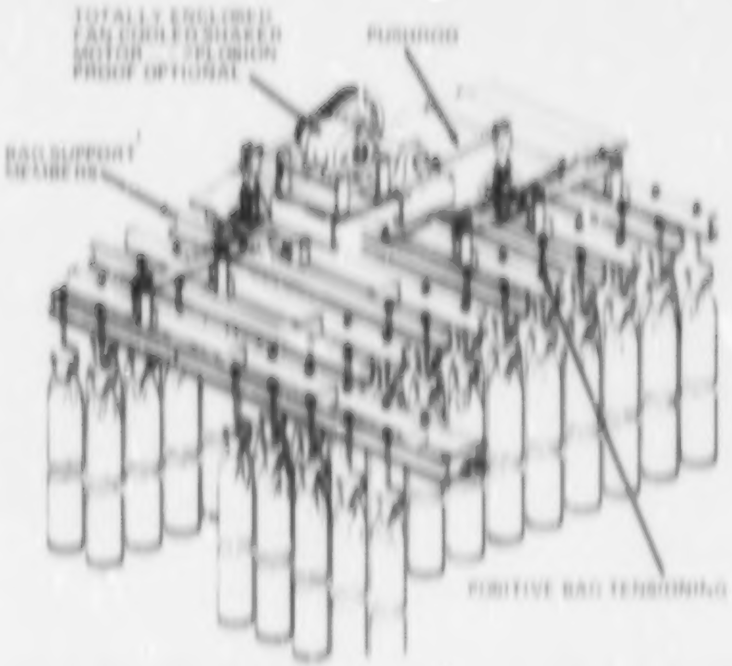

TOTALLY ENCLOSED FAN COOLED SHAKER MOTOR — EXPLOSION PROOF OPTIONAL
PUSHROD
BAG SUPPORT MEMBERS
POSITIVE BAG TENSIONING

FIGURE 57. FILTER BAG HOUSE WITH MECHANICAL SHAKING (COURTESY BUFFALO FORGE)

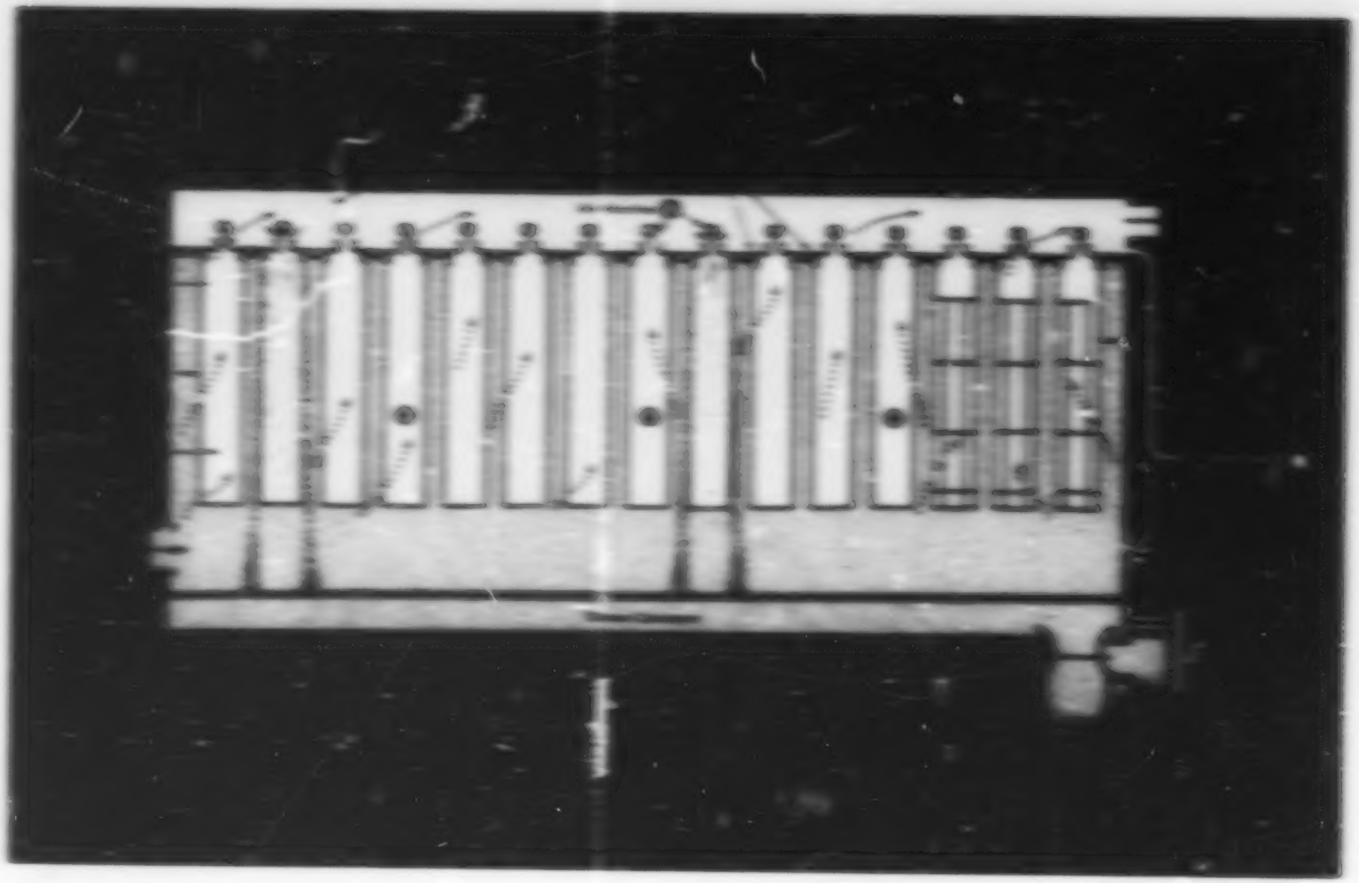


FIGURE 58. FILTER BAGHOUSE WITH AIR PULSE SHAKING
(COURTESY CE–AIR PREHEATER)

There is no apparent reason why a fabric filter will not easily meet any existing particulate standard based on dry catch. The lack of significant use in incinerators may be due to various factors:

- dramatic sensitivity to temperature
- large space requirements
- difficult maintenance
- significant operating costs

The sensitivity of fabric filters to temperature is due to inability to withstand high temperatures (up to about 260 C or 500 F for the best fabrics); and low temperatures, where moisture adsorption and condensation will occur, blinding the bags and restricting flow. Operation consistently at temperatures near the fabric high temperature limit may result in premature failure and frequent costly replacement, while even an occasional excursion above the temperature limit may cause failure or burnup of bags. Obviously, a well designed, carefully operated system to reduce and control flue gas temperature is an important part of any baghouse design.

Due to the large number of bags, baghouses ruquire larger space than scrubbers (excluding the wastewater system), but perhaps comparable space compared to precipitators. Maintenance is difficult because hundreds of bags are tightly spaced in a single housing. Physically finding and replacing broken bags is a dirty, difficult job. Complicated electronic and pneumatic timing and cycling devices for cleaning need specialized service.

High operating costs for baghouses are due both to the maintenance problem and to significant pressure drops across the bags. Operating costs are generally lower than for high efficiency scrubbers, but greater than for electrostatic precipitators.

A pilot plant baghouse was operated with some success around 1959. One recent commercial installation on a municipal incinerator has apparently been operating reasonably successfully.[28] Pertinent data are presented in Table 67.

Selection of Particulate Air Pollution Control Systems

To choose between electrostatic precipitator, scrubber, or fabric filter systems for particulate removal from incinerator gases, parameters should be compared to each specific situation.

- Initial Cost
  Including cooling systems, fans, stacks, waste disposal, and other items dependent on the method of particulate control.
- Operating Costs
  Including power, water, maintenance, labor, and waste disposal.

Table 67

OPERATING AND DESIGN PARAMETERS FOR FABRIC FILTER BAGHOUSE ON MUNICIPAL INCINERATORS[70]

Air Flow, cubic meters/min (CFM)	5090 (180,000)
Air Temperature, C (F)	260 (500)
Fabric	glass fiber
Air/Cloth Ratio, cubic meters/min/sq.meter (CFM/ft^2)	0.61 (2/1)
Bag Size,	
diameter, meters (inches)	0.14 (5.5)
length, meters (feet)	4.27 (14)
Number of bags (approx.)	4350
Method of cleaning	reverse air
Design pressure drop, mm Hg ("H_2O)	3.7-5.6 (2-3)

- Reliability
  Considering best possible estimates for downtime; the effect of downtime on other operations, sensitivity to upsets and ranges of operating conditions; possible degradation of performance with age, and problems which are induced in associated equipment.

- Environmental and Other Considerations
  Including ability to meet and exceed emission standards, removal of non-particulate pollutants, effect on the air quality of surrounding areas, the possibility of undesirable plumes, and the availability of facilities for waste disposal.

The initial cost for particulate control systems tends to be comparable when the complete system is considered, e.g., including gas coolers, hoppers, and conveyors for precipitators; allow metal construction, alkali addition, water supply, wastewater disposal, water vapor plume control for scrubbers; gas coolers, hoppers, conveyors, and pulse air supply for baghouses. However, a definitive estimate is necessary where cost is a primary consideration.

Energy requirements probably represent the single most important difference between systems. Because of low pressure drops through an electrostatic precipitator, the total energy requirements are low, even though power is required for the corona discharge and the rappers and heaters. Fabric filter pressure drops are higher, requiring more energy, but scrubber energy requirements is by far the greatest of the three systems. Table 68 illustrates this difference. The importance of differences in energy requirements is at least partially dependent on the degree of energy recovery practices in the incinerator and the availability of this energy for internal use.

Since all of these systems are highly automated, operating labor requirements are essentially comparable and low when the systems are operating properly. Maintenance material and labor requirements for all of these particulate control systems can be very significant when designs and preventive maintenance are inadequate. Thus, differences between systems may be less important than the care which is tendered toward adequate design and operation.

Acid dew point corrosion of metal surfaces can be a problem in all cases, but is more likely to occur when gases are cooled with spray water (rather than with steam boilers), such as is sometimes done ahead of either precipitators or baghouses, and always an integral part of scrubber operation. Serious buildup of pressure drop and plugging can be serious problems with scrubbers or baghouses, but seldom occur with precipitators. Problems of hopper operation, which can occur with baghouses and precipitators, are obviously not a part of scrubber operations. Moderate excursions of temperature may have relatively minor effects on precipitator and scrubber operations, but can have drastic short or long term effects on filter bags, necessitating frequent changes which require significant labor and downtime.

The performance of all of the particulate control systems considered here can, at times, deteriorate. Dust buildup on either discharge or collection electrodes will cause diminished precipitator performance. Discharge electrodes in precipitators are subject to deterioration and breakage, sometimes shorting out a section of the precipitator and reducing its effectiveness.

Table 68

AN ILLUSTRATIVE COMPARISON OF ENERGY REQUIREMENTS FOR PARTICULATE CONTROL SYSTEMS*

System	Gas Motivated Scrubber		Fabric Filter		Electrostatic Precipitator	
Gas pressure drop mmHg ("H_2O)	28.0	(15.0)	9.3	(5.0)	1.9	(1.0)
	KW per 1000 m^3/min. (hp/1000 CFM)					
Fan Power	103.2	(3.92)	34.5	(1.31)	6.8	(0.26)
Pump Power	2.1	(0.08)	-	-	-	-
Electrostatic Power	-	-	-	-	15.8	(0.6)
Total Power*	105.3	(4.00)	34.5	(1.31)	22.6	(0.86)

* This table is based on a hypothetical calculation for approximately equivalent particulate removal efficiency. It does not necessarily include sufficient fan power for all furnace and duct pressure drops. Fan efficiency is approximately 60%. Power for heating hoppers (electrostatic precipitators, baghouses) or for tracing water lines (scrubbers) not included. These are variable depending upon design and location.

Hopper bridging can cause problems in both precipitators and baghouses. The development of breaks in filter bags can have drastic effects on baghouse performance. Deterioration in scrubbers can be caused by failure of spray nozzles, mist eliminators, poor pump performance, and other means.

Dry flyash disposal, as usually practiced with electrostatic precipitators and baghouses, is considered advantageous, but, unless the flyash is carefully handled, a considerable amount of fugitive emission can occur. The removal of solids in a slurry from scrubbers is less objectionable with incinerators than in other applications because this system can be integrated with the residue system for common water recycle and residue disposal facilities.

As noted earlier, the scrubber has at least one major advantage over dry methods for particulate removal. This advantage is the ability to simultaneously remove a significant portion of the gaseous emissions. However, present regulations do not require this control, and, if later necessary, it is possible to add efficient, low energy gas scrubbers such as packed column or other types following the particulate control device. To plan for this possibility, it is important to provide sufficient extra space and some static pressure allowance in the fans. The advantage of simultaneous gaseous emission control can also be met by using wet electrostatic precipitators as is done in certain other applications.

The major drawback to scrubbers, in addition to the high energy requirement, is the formation of visible moisture plumes and the possibility of icing and condensation problems so caused. This problem is discussed in a subsequent section.

The foregoing discussion has been designed to show that each approach to particulate control has certain advantages and disadvantages. However, sufficient information is available to allow a logical selection based on careful cost and technical feasibility studies. Electrostatic precipitators have been chosen for most recent projects.

Combined Refuse/Fossil Fuel Firing

When firing prepared refuse with coal in an existing boiler, it will usually be necessary to adapt the available air pollution control equipment to the new mode of operation. In most coal-fired boilers particulate control is accomplished by high efficiency electrostatic precipitators. It is expected that in many cases these precipitators can be used for combined firing with little or no modification. However, where relatively low sulfur coal is being fired with exit flue gas temperatures greater than about 270 to 280 F, the addition of low sulfur refuse may introduce, or make worse, resistivity problems due to the lack of sufficient sulfur trioxide conditioning agent naturally present from the coal sulfur. The little data which is available on this point strongly suggests this possibility.[15,32] In this situation, gas conditioning with sulfur trioxide or similar additives, or extensive precipitator modification might be necessary to meet emission regulations.

The firing of refuse with oil, which is being considered, may require installation of special particulate control equipment, if the boiler is not already so equipped. Some oil fired boilers have been converted from coal and do have bottom ash removal, mechanical separators and/or electrostatic precipitators which could be useful, but careful analysis is required for each situation to assess potential air pollution control and other problems.

The preparation of refuse for firing is discussed in Chapter VII. Emissions from the dust collection cyclones used with the hammermill and air classification system in a St. Louis demonstration plant have been measured.[25] These measurements indicate that careful design and operating practices will be necessary to avoid emissions from unit operations used to convert solid waste to fuel.

Pyrolysis

The pyrolysis plants which are being built or considered can be separated into two classes as far as air pollution control is concerned. First, there are those plants which produce primarily fuels for sale and use in other locations. These plants should not be prone to very serious air pollution control problems, except for those problems, such as odors, generally associated with handling municipal solid waste, and for possible emissions from miscellaneous special unit processes such as shredding, air classifying, and drying. The second class of plants are those that internally burn the fuel produced to make steam for sale. In these plants, particulate control could be as difficult as in incinerators, with evaluation criteria similar to those already discussed.

Since pyrolysis processes available are primarily proprietary, the vendors have been specifying the entire plant, including air pollution control systems. This situation is expected to continue for some time. The limited information available on air pollution control for commercially available pyrolysis processes is covered in Chapter XI.

Gaseous Emissions

The overwhelming quantity of stack emissions from incinerators consists of relatively innocuous gaseous combustion products, namely carbon dioxide (CO_2) and water (H_2O), and unused oxygen (O_2) and inert nitrogen (N_2) from the combustion air. The relative and absolute quantities of each are determined primarily by:

- the composition of the refuse
- the amount of excess air used (deliberately as well as through leakage)
- the amount of air and/or water used for flue gas cooling and cleaning.

Figure 69 shows typical gas emissions as a function of excess air. Extensive data for a range of solid waste compositions, excess air, and gas cooling possibilities have been generated and reported,[7] but as explained in the reference cited, calculated gas flow rates are somewhat high and temperatures lower than would actually be expected. Table 69 shows typical gas compositions for two types of incinerator and air pollution control combinations. These gases are generally of little concern, except for water plume formation and insofar as certain air pollution standards are based on a specific gas composition, e.g., 12 volume percent CO_2. Emissions of various inorganic and organic contaminating gases are of concern and are considered in subsequent sections of this Chapter.

Water Vapor Plume Control

High water vapor concentrations, under certain weather conditions, will produce a visible plume. Given the temperature and water concentration in the stack gas, the ambient temperature and humidity conditions under which the plume will form can be predicted.[17] Water vapor plumes are not regulated, but practical considerations, such as icing of nearby roads or buildings, fogging over roadways, or psychological reaction to a visible emission, may necessitate at least some degree of plume control.

As noted earlier, visible stack exhaust plumes will be experienced when scrubbers are used, and may be experienced under certain weather conditions with other devices. These plumes are caused by condensation of water vapor into fine droplets when the hot, humid stack gases contact cold ambient air. Under some circumstances, it may be necessary or desirable to eliminate the visible plume.

The determining factors in plume formation are

- stack gas temperature
- stack gas water concentration (humidity)
- ambient air temperature
- ambient air humidity

Since ambient air conditions obviously are not controllable, the only methods of water vapor plume control are to increase stack gas temperature and/or to reduce stack gas water concentration. Control methods may be designed for continuous or intermittent use, as desired.

Stack gas temperature can be increased by a stack burner which injects very hot combustion gases directly into the stack, by mixing with a warmer gas from another source, or by heat exchange with a source of heat (for example, steam or furnace flue gases). The first two approaches may also achieve a reduction in water concentration. Although relatively simple, these methods are undesirable because of auxiliary fuel requirements. The increased gas flow also may require a larger diameter stack.

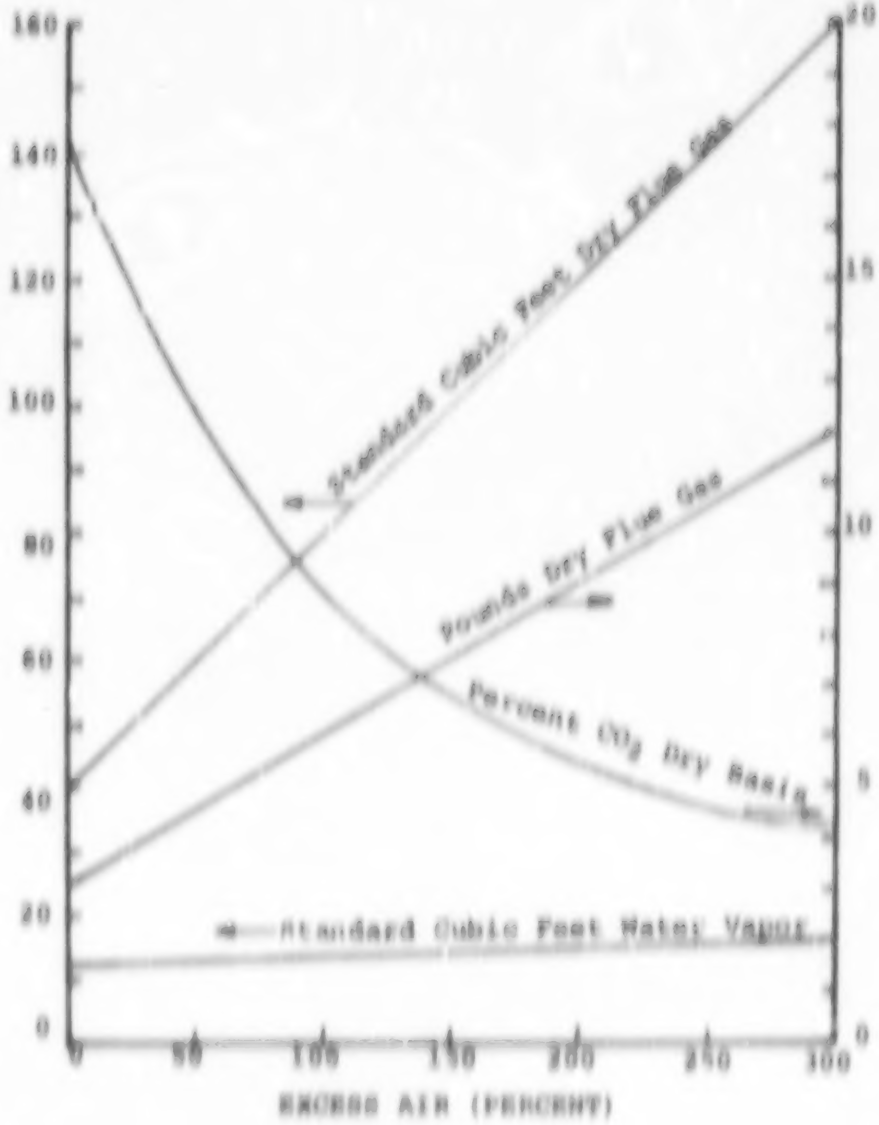


FIGURE 58. GROSS PRODUCTS OF COMPUSTION PER POUND OF TYPICAL WASTE[19]

Table 69

TYPICAL GAS COMPOSITION FOR CONVENTIONAL AND STEAM GENERATING INCINERATORS

	Type of Incinerator	
	Waterwall[30]	Refractory[31,32]
Refuse Heating Value (HHV) Cal/g (BTU/lb)	2420 (4360)	—
Refuse Firing Rate, MT/hr (ST/hr)	15.2 (16.7)	8.4 (9.2) (Rating)
Air Cooling/Air Cleaning Method	Boiler/Electro- static Prec.	Caustic Scrubber
Excess Air, %	71.7	100 (estimated)
Stack Exhaust		
Temperature, C, (F)	211 (411)	57-77 (135-170)
Volume % CO_2, wet basis (dry basis)	9.1 (10.5)	3.7-3.2 (4.8)
Volume % O_2, wet basis (dry basis)	7.8 (9.0)	10.1-8.6 (13.0)
Volume % N_2, wet basis (dry basis)	69.8 (80.5)	64.2-58.2 (82.2)
Volume % H_2O, wet basis	13.3	22-30
Flow, CM/min @ Temperature (ACFM @ Temperature)	2400 @ 211 C (84,700 @ 411 F)	2119 @ 77 C (74,800 @ 170 F)

Heat exchange with the hot furnace flue gases is expensive because of the large amount of heat exchange surface required. However, if the heat exchange surface could be placed so as to remove heat directly from the combustion zone, it is theoretically possible to decrease excess air normally required for temperature control in conventional incinerators, thus increasing furnace capacity as limited by solid handling capability. At least one system has been built for heat exchange with hot flue gas, but none are known to operate by extraction of heat directly from the combustion zone. Unlike the systems discussed in the previous paragraph, indirect heat exchange does not decrease moisture content, which could even increase if excess air is reduced.

Plume control by reducing stack gas moisture content may be even less attractive than the methods described. All things considered, plume control should be avoided unless a very serious local environmental condition, such as road icing, results. In this case, intermittent control with the use of fuel for a brief duration may be the best choice. Such systems have been used on power plants.

Carbon Monoxide and Organic Gas Emissions

Poor combustion can result in emissions of carbon monoxide, hydrocarbons, oxygenated hydrocarbons, and other complex compounds. Some of these emissions are the source of odors which used to be associated with incinerator operation. While no data have appeared for modern facilities, improved combustion efficiency and control probably have reduced these emissions to insignificant proportions. Table 70 lists some measurements which have been made on older incinerators.

Handling and storage of solid waste, as well as furnace leakage, often can create odors which may be detected both within the working areas of the facility and in nearby residential or commercial areas.

No specific emission regulations exist which would control these emissions from incinerators. However, ambient air quality standards for carbon monoxide and hydrocarbons do exist (Table 71).

Inorganic Gas Emissions

Minor quantities of sulfur oxides, ammonia, and halide gases are produced from the sulfur, nitrogen, and halide (chlorine, bromine, fluorine) content of the solid waste. Nitrogen oxides emitted may result from the nitrogen content of the waste or high temperature oxidation of nitrogen in the air. All these emissions are expected to be directionally, but not necessarily quantitatively, related to the concentration of the source element in the waste burned. Table 18 shows typical quantities emitted.

Hydrogen chloride (HCl) has been of particular concern because of increasing emissions due to increased disposal of polyvinyl chloride (PVC) and other halide containing plastics and aerosols, because of possible health

Table 70

CARBON MONOXIDE AND ORGANIC GAS EMISSIONS FROM INCINERATORS

Gaseous Compound	Refractory* Incinerator[29]	Refractory Incinerator With Caustic Scrubber[31]	Refractory Incinerator[34] With Scrubber	Refractory Incinerator[34] Without Scrubber
	Concentration in Emitted Gas, ppm by volume			
Carbon monoxide	<700-900	<25	<1000	<1000-3000
Hydrocarbons**	0.5-240	0	0	0
Oxygenated Hydrocarbons				
Aldehydes⁺	0.3-0.2	0.12	1-9	1-22
Organic acids	0.7-7.0	1.6	-	-

* probably with spray chamber

** reported as methane

⁺ reported as formaldehyde

Table 71

FEDERAL AMBIENT AIR QUALITY STANDARDS FOR GASEOUS POLLUTANTS

	Primary Standard	Secondary Standard
Carbon Monoxide	10 milligrams/m^3 (9 ppm) maximum 8-hour concentration*	same as primary
	40 milligrams/m^3 (35 ppm) maximum 1-hour concentration*	same as primary
Hydrocarbons	160 micrograms/m^3 (0.24 ppm) maximum 3-hour concentration (6-9 AM)*	same as primary
Photochemical Oxidants	160 micrograms/m^3 (0.08 ppm) maximum 1-hour concentration*	same as primary
Sulfur Oxides+	80 micrograms/m^3 (0.03 ppm) annual arithmetic mean	1300 micrograms/m^3 (0.5 ppm) maximum 3-hour concentration
	365 micrograms/m^3 (0.14 ppm) maximum 24-hour concentration*	
Nitrogen Dioxide	100 micrograms/m^3 (0.05 ppm) annual arithmetic mean	

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* not to be exceeded more than once per year
+ measured as sulfur dioxide

effects, and because of the possibility of corrosion, especially of tube metal surfaces in steam generating systems (discussed in Chapter X). Table 16 shows an approximate correlation between the PVC content of the refuse and HCl emissions. It is believed that almost all of the chlorine in PVC (greater than 50 percent chlorine) is converted to HCl but that some of the HCl reacts with particulate matter and is removed by particulate control equipment.

Hydrogen chloride and fluoride, sulfur oxides, nitrogen oxides, and some oxygenated hydrocarbons are acidic with at least some solubility in water. Therefore, when flue gas is exposed to liquid water, such as in a quench chamber or scrubber, or even due to cold wall condensation, very corrosive conditions exist which will attack even stainless steel. Neutralization, with caustic or other alkaline materials, both enhances removal and helps prevent acid attack in wet systems.

There are no specific Federal emission standards for gaseous emissions from incinerators, but ambient air quality standards do exist for sulfur oxides, and nitrogen dioxide (Table 71). Though nitrogen oxide and sulfur oxide emissions from power plants are limited by some regulatory standards, no such limitations are known to exist for incinerators.

As shown in Table 72, ammonia is sometimes reported at a constituent of incinerator effluent gases. The ammonia may result from refuse decomposition reactions. Wet pollution control systems would be expected to remove at least some ammonia, especially where the water is acid or near neutral. No specific regulations exist for ammonia control. Although information is only minimal as to the extent of ammonia emissions, it does not appear to be a serious problem.

Control of Gaseous Emissions

Carbon monoxide and hydrocarbon emissions, including odorous compounds, are effectively controlled by a well designed combustion chamber, and careful control of operating conditions. Odors from waste handling and storage can be controlled by drawing the combustion air into the plant through these areas so that the odor-bearing gases will be burned in the incinerator. Similarly, leakage from the furnaces can be prevented by maintaining a slight negative pressure within.

Inorganic gaseous emissions do exist in relatively low concentrations, but they need not be controlled in the absence of specific regulations. Where water scrubbers are used for particulate control, significant removal of hydrogen chloride, sulfur dioxide, and nitrogen dioxide (but not nitric oxide) will occur. Where only electrostatic precipitators or baghouses are used for particulate control, only a small amount of these gases will be removed, limited to that quantity which reacts with or adsorbs onto particulates.

Monitoring

Although there are no specific requirements for air pollution monitoring, the following stack monitors may be useful for operational as well as environmental purposes and are often used.

Table 72

SULFUR OXIDE, AMMONIA, NITROGEN OXIDE, AND HALIDE GASEOUS EMISSIONS FROM INCINERATORS

	Concentration in Emitted Gas, ppm by volume						
	Refractory Incinerator[31]				Refractory Incinerator[33] At Furnace Exit		
Gaseous Compound	With Scrubber	Without Scrubber	"Refractory*" Incinerators[29]	Refractory Incinerator With Caustic Scrubber[31]	"Normal Refuse"	2% PVC Added	4% PVC Added
Nitrogen Oxides	22-44	58-82	-	2.6	23-25	40.6	46.2
Sulfur Oxides	-	-	54-109**	14.6#	33-40	37.5	38.6
Ammonia	-	-	-	28.6	-	-	-
Chlorine	-	-	-	1.9		none detected	
Hydrogen Chloride	-	-	38-113	11.3	465-732	1990	3030
Hydrogen Fluoride	-	-	0.6-0.9	-	0.9-2.3	4.6	2.8

* Probably with spray chamber

** $SO_2 + H_2SO_4$

# SO_2 only

- opacity (smoke density)
- oxygen
- carbon dioxide
- combustibles
- television

Opacity meters measure the transmission of light through the stack gases. They can be used as an indicator of whether particulate emission standards are being met, as well as to detect periods of poor combustion, characterized by "smoke-laden" flue gas.

Oxygen and/or carbon dioxide monitors measure these chemical constituents in the flue gas. They are useful as indicators of the amount of excess air being used, although usually only one or the other is provided. Combustible gas monitors measure organic content, and can be also used as an indicator of furnace combustion conditions. Television cameras are useful for monitoring smoke, water vapor plumes, and general surveillance.

In order to insure successful operation of monitoring instruments, provision for and practice of regular care, cleaning, calibration, and other maintenance are essential.

Stacks

Traditionally, stacks have been used to provide natural drafts for the furnaces as well as to disperse the "noxious" gases from previously uncontrolled incinerators. With the use of fans in modern facilities, the draft aspects of the stacks are less important. However, even with modern air pollution control devices, stacks are generally still required to disperse residual pollutants in order to avoid high ground level concentrations. Sophisticated dispersion modeling techniques, usually computerized, can predict air quality resulting from utilizing various stack heights and diameters, and can even aid in stack location to avoid "downdraft" effects due to buildings and hills. As discussed earlier, the choice of the number of stacks can also be affected by opacity considerations.

If water vapor plumes are experienced, stacks also function to disperse them before impinging on surfaces where icing or condensation can be harmful.

Numerous stack designs and materials, ranging from ordinary steel to corrosion resistant steels (e.g., Corten, stainless) to brick and mortar have been used, all with reasonable performance and expected lives. Stacks with hermetically sealed inner liners to prevent condensation and chemical attack have been used for those installations requiring especially long-lives stacks.

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CHAPTER XV

ACCEPTANCE EVALUATION

The fundamental purpose for accentance evaluation is to assure the owner that the newly built thermal processing facility will adequately dispose of the municipal solid wastes for which it has been designed. Success in meeting schedule, cost, safety, health, aesthetic, reliability, and environmental criteria will depend upon the adequacy of the owners planning, the consulting engineer's design, and the contractor's performance. Planning and design work should be completed and evaluated prior to the signing of a construction contract; changes after this point are usually costly and should be made only when imperative.

This discussion will consider only the more pragmatic purpose of acceptance evaluation, which is the determination that the thermal processing system performance meets specifications, and that all provisions of construction and sales contracts are being met. The method or means of acceptance evaluation are provided for in contract terms. The American Society of Mechanical Engineers (ASME) has been preparing test codes for measuring the efficiency and performance of incinerators. These codes, plus the judgment of consulting engineers and information obtained from recent experience by others, can provide the technical basis for contract terms.

Project Management

Acceptance evaluation procedures are influenced by the nature of the planning/design/manufacturing/construction team. A typical team consists of the owner (municipality), the consulting engineer, an incinerator manufacturer, and a general construction contractor. Other arrangements might include separate contracts for chimneys, site work, cranes, and other major pieces of equipment. Where the team becomes complicated, the owner or the consulting engineer must supply formal project management services to coordinate construction work and to handle acceptance evaluation. On the other hand, some facilities are designed and built on a turnkey basis by a manufacturer who is willing to take complete project responsibility.

The most meaningful overall performance guarantees are available on a turnkey basis, but the value of guarantees should not be overrated. Although the punitive effect of guarantees is real enough to the supplier, liability is usually limited, subject to costly litigation, and seldom covers the owner's true costs. Project organization should be focused on obtaining reliable engineers and suppliers and providing tight project management, while at the same time obtaining the best possible guarantees. The designer, who may be the consulting engineer or a manufacturer, carries the major responsibility for overall performance.

Contracts should incorporate detailed specifications and timetables to avoid misunderstandings between the owner and the supplier. The specifications will normally cover critical design features, selection and quality of components, workmanship, installation responsibility, performance guarantees, and inspection and testing procedures. Other specifications for the protection of the supplier may also be covered, including adequate space, utilities, maintenance, access, and safety devices. Performance guarantees should cover ranges of possible conditions when necessary to allow for variability and uncertainty in basic data. For example, guaranteed burning efficiency and steam generation for a new incinerator was tied to heating value in the performance requirement shown in Table 73. "Burnout" or percent organics in the residue is an important measure of performance which merits a guarantee requirement in contracts.

Particulate emission standards and test procedures for incinerators are provided in EPA's "Standards of Performance for New Stationary Sources,"[2] and can be included as a contract provision. Heavy metal emissions, such as compounds of lead and mercury, which may occur in vapor, liquid, or solid form, could also be limited by guarantees, but have not been done so to date. Gaseous emissions which could be, but are not commonly, specified include odors, carbon monoxide, hydrocarbons, sulfur oxides, nitrogen oxides, and hydrogen chloride. Future incinerator designs could incorporate features to minimize some of these gaseous emissions. For example, nitrogen oxide emissions might be minimized through carefully controlled combustion, or hydrogen chloride might be removed by scrubbing. Thus, it could become necessary to include test procedures for these gases, or others, in the contract. One important source of data for both emission and air quality testing procedures is the Quality Assurance and Environmental Monitoring Laboratory located at EPA's National Environmental Research Center in Research Triangle Park, North Carolina. Some States, for example Texas,[3] have recommended methods for gas analysis. The contract should also specify the organizations which will carry out the indicated tests.

Water quality test procedures may also become contract provisions. Accepted methods of analysis have been published by the U.S. Environmental Protection Agency (EPA),[4] American Public Health Association,[5] and American Society for Testing and Materials (ASTM).[6] These contract provisions may cover temperature, pH, BOD, suspended solids, dissolved solids, and other accepted water quality measurements.

EPA also has manuals available which cover monitoring of wastewater[7] and analytical quality control in laboratories.[8] ASTM standards cover many other materials important in thermal processing, including petroleum products and fuels (for pyrolysis processes) and building materials.

Quality criteria and testing procedures for pyrolysis units have not yet been established, but close attention will have to be given to combustible gas, liquid, and solid product qualities where needed to meet internal uses or sales contracts. Procedures will also be needed for resource recovery products, and for air, water, and noise standards to be met in shredding, separation, and resource recovery steps.

More complex contract provisions may provide formulas for the amount of liquidated damages as a function of the performance of thermal processing

Table 73

PERFORMANCE REQUIREMENTS FOR SEVERAL TYPES OF MIXED SOLID WASTE[1]

Nominal Calorific Value, Btu/lb	6,500	6,400	5,000	4,000	3,000
Calorific Value (High Heating Value), Btu/lb	6,495	6,072	5,070	4,328	3,026
Refuse Throughput per Furnace, lb	22,220	25,380	28,000	30,200	27,000
Moisture Content in Refuse, percent	14.7 to 9.7	18 to 13	25 to 20	32 to 27	39 to 34
Non-Combustible Content in Refuse, percent	14.0 to 19.0	16 to 21	20 to 25	24 to 29	28 to 33
Combustible Content in Refuse, percent	71.3	66	55	44	33
Flue Gas Temperature at Electrostatic Precipitator, °F	470	450	470	460	440
Guaranteed Overall Burning Efficiency, percent	68.5	67.0	65.0 to 66.5	60.0 to 60.5	52.5 to 53.0
Steam Generated per Pound of Refuse (minimum), lb	4.3	3.9	3.2	2.3	1.5 to 1.0

CONSTANTS:
Ambient Temperature = 70°F
Relative Humidity = 75 percent

Feed Water Temperature = 220°F
Superheated Steam Pressure = 250 psig
Superheated Steam Temperature = 450°F

unit during the acceptance test, and as a function of the days of uncompleted contract work beyond the specified completion date. Early completion may be rewarded by a specified bonus per calendar day. Other provisions which may affect acceptance evaluation will cover:

- payment schedules and tax payments.
- applicable codes and standards (e.g. ANSI, NEMA, ASME, ASTM, IEEE, etc., including any local or other special standards).
- shop tests required for certification and proof that the equipment conforms to all applicable codes and standards, including provisions for cost, owner representation, and certified copies of test data.
- shop inspection.
- submission of certified drawings.
- instruction books.
- startup assistance and operator training.
- spare parts and lists of recommended spare parts.
- cleanliness, painting, and corrosion protection of equipment.
- special tools.
- auxiliary equipment such as controls, protective accessories, safety devices, and measuring instruments. (All controls should be specified for fail safe operation.)
- quality assurance programs.
- liability.
- performance bonds.
- conformity to occupational safety and health standards.
- construction schedule.
- deviations from plans, schedule, and specifications.
- warranties and maintenance standards for equipment items.
- arbitration of disputes.
- escalation of byproduct prices, e.g., escalation of steam or fuel prices with published fuel prices.

A "shakedown" period between completion of the facility and final acceptance testing or evaluation is provided for the protection of both the owner and the contractor. This period may range from one month to as long as one year.

Sufficient time is allowed for evaluation during actual operation when deficiencies may be expected to occur, for on-the-job training for the owner's operators, and for detection of equipment items which require excessive maintenance. It also allows the contractors to correct deficiencies without further monetary penalty.

Basic contract outlines should be available prior to bidding, since its provision will affect the bidders response. However, allowance must be made in bidding procedures for modifications and alternative proposals. Contracts must be reviewed by technical personnel as well as by the owner's administrative and legal staff to assure that the terms are comprehensive, self-consistent, consistent with Federal, State and local regulations, and that they properly spell out all necessary responsibilities and liabilities.

Acceptance Tests

The procedures and sampling equipment being used by the Office of Solid Waste Management Programs (OSWMP) of the Environmental Protection Agency can provide a basis for final acceptance evaluation for incinerators.[9] The OSWMP document cited covers:

- preliminary test arrangements.
- charging and operation.
- incoming solid waste characterization.
- residue and grate siftings characterization.
- flyash and breaching fallout characterization.
- characterization of process and wastewaters.
- stack sampling.
- incinerator efficiency.

No similar document is yet available for pyrolysis facilities, but some of the items cited above can be useful for this purpose. As stated previously, test codes for incinerators are under development by ASME (New York City).

In addition to the overall plant acceptance, proper evaluation procedures will cover various components of the final plant including foundations and concrete structures, buildings and other structures, pressure vessels and piping, non-coded vessels and piping, rotating equipment, heat exchangers, instrumentation, electrical equipment, mobile equipment, safety equipment, communications equipment, personnel, and sanitary facilities, maintenance facilities, roadways, landscaping, parking facilities, conveyors, stokers, grates, cranes and hoists, scales, refractories, chimneys, laboratory equipment and facilities, drainage, wastewater treatment, and air pollution control. Shop and field inspections should confirm that materials of construction have been supplied as specified, component and code requirements have been met, workmanship is satisfactory, and that schedules are being met. Defective construction and equipment should be identified at the earliest possible time to minimize startup delays and costly post-completion corrections. Proper records must be kept by those responsible for acceptance evaluation.

Preliminary tests on components in place should precede the overall acceptance test. However, final performance tests are best done under conditions of full operation where maximum thermal and vibrational stresses are normally encountered. Periodic inspections of all equipment externally and internally should be made during the "shakedown" period.

Everything possible sould be done to schedule a fullscale acceptance test early in the "shakedown" period, so that sufficient time is available for corrections, if necessary. All interested parties should be invited to observe the acceptance test, including the consulting engineer, manufacturers of major equipment (e.g. air pollution control, furnaces, fans, resource recovery), and representatives of regulatory agencies. Contracting for assistance of unbiased third parties for pollution control and other testing is recommended for the final acceptance test.

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CHAPTER XVI

SOLID WASTES THAT REQUIRE SPECIAL CONSIDERATION

Municipal refuse often contains wastes which are unsuitable for or require special consideration for disposal in incinerators or other thermal processing systems. These special wastes can be minimized by collection restrictions, thereby diverting them to landfill or other disposal methods. Included as wastes that require special consideration are bulky items, obnoxious and hazardous materials, high and low heating value combustibles, sewage sludges and various industrial wastes. They can create difficult or even catastrophic problems. Some can be handled readily in amounts sufficiently small so as to be diluted to a harmless level by the balance of the solid waste; others, for example bulky steel scrap, can cause damage even as isolated items.

Bulky Wastes

Typical bulky wastes are shown in Table 74. Bulky wastes require special consideration because they may.

1. Overload, clog, or jam conveyors, grates, and other moving equipment (e.g. stoves, branches, mattresses).

2. Be physically too large to enter or leave the thermal processing unit (e.g. refrigerators).

3. Contain very little combustible materials.

4. Be so dense as to smolder and prevent complete burnout of other wasts (e.g. tires and rugs).

Table 74

EXAMPLES OF BULKY WASTES

Logs, branches, stumps
Furniture (metal, wood, plastic)
Mattresses, bed springs
Crates, boxes, skids, pallets, lumber
Tires, wheels, other auto parts
Stoves, washers, dryers, refrigerators, water heaters
Lawn mowers, garden equipment
Rugs
Asphalt or concrete chunks
Mixed demolition waste

Included in bulky waste is the estimated five to ten percent of municipal solid waste which is combustible but measures over 1.2 meters (4 ft.) in length and eight centimeters (3 in.) in diameter.[1] Quantity and types of bulky waste will vary greatly from community to community and season to season, depending on collection practices, industrial and commercial activities, residential makeup and age, and other factors. A distribution of bulky wastes in a New York City sample is shown in Table 75. Some data on composition, density, quantity, fuel value, proximate analysis, ultimate analysis, combustion air requirements, and smoke producing propensities of oversized wastes have been developed.[1]

Table 75

WEIGHT DISTRIBUTION OF OVERSIZED WASTE
(NEW YORK CITY)[1]

	Weight Percent of Total Oversized Waste
Trees, stumps, brush	1.3 to 9.6
Furniture and fixtures	1.2 to 40.0
Lumber and remodeling waste	6.3 to 36.0
Cardboard and paper	1.0 to 4.1
Rubbish and other	15.8 to 40.8
Non-burnable	18.7 to 38.8

Even in modern thermal processing systems, bulky wastes are often separated, either at the collection point, or at the plant. Although it varies from installation to installation, separation usually is "manual," requiring a human decision and action. Separation by laborers at the pit, hoppers, or conveyors, or by the crane operator is not unusual. Salvage is sometimes practiced to at least partially offset separation cost.

Disposal in landfills is acceptable where suitable sites are available. Volume requirement is high, however, and open burning of combustibles to reduce the volume is now permissible only under very unusual circumstances. Special incinerators to handle bulky wastes have been used, but the costs of a separate facility may not be justified if alternative disposal means are available.

Modern approaches to the problem of bulky wastes include shredding, either mixed with other solid waste in a feed preparation or resource recovery system, or separately for adding-back to unshredded waste for incineration. Obviously the shredder should be of sufficient size and durability. Shredding is covered more fully in Chapter XVII, Resource Recovery.

Hazardous Wastes

Highly flammable, explosive, toxic, radioactive, and environmentally disruptive materials may be classified as hazardous. Wastes that produce such materials even thermally processed may also be classified as hazardous. The health and safety of operating and nearby personnel, and protection of equipment and of the environment, require that hazardous wastes be given special treatment.

Typical hazardous wastes are listed in Table 76. It is impossible to completely prevent their entry into the main municipal solid waste stream. However, since almost all of these materials can be handled in quantities where their effects are diluted to a harmless level, provision should be made to minimize their quantity. This can be most effectively done by restriction at the collection level; preferably by special pickup with segregation and labeling of the hazardous wastes; or by requiring special pickup and disposal by licensed operators. This approach can be effective because the most important sources of such wastes are industrial plants.

Table 76

EXAMPLES OF HAZARDOUS WASTES

Paint, solvents, gasoline, kerosene, oils
Highly flammable plastics, dusts, shavings
Explosives and pyrophoric materials
Organic chemicals, including toxic materials such as pesticides, phenols, and chlorinated compounds
Other toxic materials such as mercury, lead, and arsenic compounds, and wastes which contain appreciable amounts of toxic materials (e.g. lead-containing waste crankcase oil and paint)
Acids, caustics, other reactive chemicals
Biologically active materials e.g. pharmaceutical wastes and some pathological wastes from veterinarians and hospitals
Radioactive wastes
Pressurized containers
Contaminated containers

Solvents, oils, organic chemicals, explosives, and other highly flammable materials present dangers of fires or explosions in trucks, pits, shredders, and feed systems, as well as presenting heat or explosive damage potential to furnaces. Organic chemicals, pesticides, toxic materials, biologically active materials, acids, caustics and other similar materials present potential health and safety hazards to the operating personnel and possible environmental problems. The best protection against these hazardous materials is certainly to keep them out of the system; in actual practice that is to keep the frequency and concentration very low.

Pressurized containers, such as aerosol cans, welding gas tanks, and propane cylinders, when heated in a furnace, can explode and become missiles. Protection against these occurrences lies in both good design and education of the public and collection and operating personnel to keep these out of waste fed to thermal processing facilities.

Radioactive wastes should not be accepted, but should be disposed of by the user in accordance with Atomic Energy Commission standards. Communities where this is a potential problem could use detection devices on the solid waste feed system.

Detection of hazardous wastes after collection is very difficult, if not impossible. Severe restrictions and enforcement at the collection site appears to be the only practical method of control. Disposal at the incinerator site may only be safe and practical if dilution is possible, or if the facility has been specifically designed to handle them. Disposal at industrial waste disposal or other specially designed facilities should be considered. For example, some highly industrialized areas now have privately run waste disposal plants which accept and dispose of difficult wastes, mostly from industrial plants on a toll basis. The safety and environmental problems are then dealt within one centralized location.

Plastics

Ordinary plastic components of municipal solid waste have received much publicity, particularly concerning acid gases (hydrogen chloride and other hydrogen halides) formed during the combustion of polyvinyl chloride and other halide-containing plastics. These acid gases may contribute to equipment corrosion, including air pollution control equipment, induced draft fans, and heat transfer surface used to generate steam, as well as to atmospheric pollution. Insufficient information is available to fully evaluate potential corrosion problems, but the many satisfactory operations suggest that such problems can be overcome by good design, and operation, for example by avoiding condensate formation and minimizing superheater tube temperatures. Even the potential for air pollution problems is unclear because of lack of data on adsorption of acid gases by flyash. In any case, no restrictions presently exist on hydrochloric acid emissions. Such emissions could be controlled by scrubbing, if necessary, but scrubbing is expensive and introduces requirements for water treatment, including neutralization.

In spite of the above, high concentration of polyvinyl chloride and other plastics, which can be caused by the introduction of industrial wastes, should usually be avoided since these may contribute to making significant the potential corrosion and air pollution problems discussed, and because the combustion characteristics of many plastics differ sufficiently from the bulk of the solid waste that carbonaceous and gaseous emissions may increase. Plastics do increase refuse heating value, contributing to energy recovery.

Halogen-containing plastics also present special problems in pyrolysis, resulting in chlorinated and halogenated organics when not separated in resource recovery systems. Nonhalogen-containing plastics such as polyethylene, polybutylene, and polystyrene obviously do not present problems of chlorinated byproducts.

Obnoxious Wastes

Examples of obnoxious wastes are provided in Table 77.

Table 77

EXAMPLES OF OBNOXIOUS WASTES

Pathological wastes (anatomical, surgical dressings, other human and animal hospital wastes)
Food and meat processing wastes
Dead animals
Odiferous chemicals

Pathological wastes from hospitals, dead animals, food and meat processing wastes, animal droppings and similar materials present potential health hazards as well as disagreeable working conditions to operating personnel. Unless specific arrangements are made, these wastes should not be routinely accepted. Satisfactory arrangements may include use of appropriate disposal packages which contain the obnoxious effects of odors, bacteria and viruses, insects, and visual and other unpleasantness.

Most hospitals have pathological waste incinerators, but wastes from medical laboratories, doctors offices, veterinary hospitals, research centers, and taxidermists may find their way into municipal solid waste, if not controlled. Restrictions through licensing may be most effective, but collection practices should also be monitored.

Most large-scale food or meat processing plants have suitable disposal facilities. Wastes from butchershops, supermarkets, fish stores, and restaurants may become troublesome if substantial and not properly packaged. Generally, however, these sources generate small quantities which can be easily handled.

Dead animals are collected from highways in significant numbers. These may be handled with care in a thermal processing unit, if not too bulky. However, landfills are often used for disposal.

If significant quantities of obnoxious wastes are generated, the thermal processing facility should be designed to handle them; a separate special facility may also be considered. Use of a truly sanitary landfill for obnoxious wastes can be satisfactory assuming proper leachate control is provided.

Sewage Sludge

Sewage sludge is the residue from treatment of raw sewage. While very large amounts of sludge are already generated, the quantity will increase very dramatically as municipalities build secondary treatment plants (under Federal grant programs). Present sludge disposal practices include:

1. Ocean dumping.
2. Landfill.
3. Incineration.

Ocean dumping presents serious problems and will most likely be eliminated as proven alternative technology becomes available. Landfill is acceptable if available. In locations where landfill is not available for municipal solid waste, it is not likely to be available for sludge. Therefore, thermal processing appears to be a possible alternative.

Many fluidized bed and multiple hearth incinerators have been used for sludge incineration, but due to the high water content and fuel requirements, operating costs are high. An approach of interest is combined sludge-municipal solid waste incineration, whereby the fuel value of the waste is used to evaporate the water from the sludge.

In a refractory incinerator, air in substantial excess over that required for combustion is used to moderate the temperature. As seen in Table 78, simultaneous burning of solid waste and the wet sludge reduces tempering air requirements. In addition to the obvious advantage of this dual function, additional benefits accrue:

1. Flue gas volume is reduced, resulting in lower air pollution control system investment and operating costs. Fans, motors, ducts, stacks and associated equipment can be relatively smaller and less costly.

2. Alternatively, furnace throughput may be increased since this generally is limited by the combustion air rate.

Another approach which deserves consideration is the use of the hot flue gas from the incinerator for pre-drying of the sludge. This obviously requires additional equipment, but does allow handling as a solid.

Table 78

COMPARISON OF CONVENTIONAL INCINERATION AND SLUDGE-MUNICIPAL SOLID WASTE CO-INCINERATION PARAMETERS

PARAMETER	CONVENTIONAL INCINERATION	CO-INCINERATION
Solid Waste, kg @ 25° C	454	454
HHV,† cal/g	2780	2780
% H_2O	22	22
% Ash	21	21
Sludge, kg @ 25° C	0	341
HHV,† cal/g	-	222
% H_2O	-	95
% Ash	-	1.4
Air, kg @ 25° C	4690	3150
normal cm/metric ton*	8950	3460
% excess	185	100
Flue Gas, kg	5050	3840
°C	870	870
Ash, °C	870	870

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* of solid waste plus sludge

† HHV = high heating value; low heating value of sludge containing 5% solids is negative.

In summary, various alternatives are worthy of consideration (though not necessarily proven):

1. Incineration of sludge and raw refuse in a refractory incinerator.
2. Incineration of sludge in a multiple hearth employing solid waste as an auxiliary fuel.
3. Combustion of sludge with solid waste in a fluidized bed incinerator.
4. Utilization of waste heat from the combustion of solid waste to evaporate moisture from sludge prior to disposal of sludge, or incineration in the same or a different combustion chamber.
5. Utilization of spray technique to inject wet sludge directly into the combustion chamber of a solid waste incinerator.

The use of solid waste incineration to aid in sludge disposal has been practiced in the past.[2,3] At least one full scale plant (in Ansonia, Connecticut) is currently practicing the fourth possibility above with some success.

It may or may not be possible to handle all of the solid waste and sewage sludge in a single system, depending on the quantities to be handled and their characteristics, especially the water content of the sewage sludge.

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2. Stephenson, J. W. and A. S. Cafiero. Municipal Incinerator Design Practices and Trends. Paper prepared for 1966 National Incinerator Conference. New York. May 1-4, 1966. American Society of Mechanical Engineers. 38 pages.

3. U.S. Environmental Protection Agency. Third Report to Congress-Resource Recovery and Waste Reduction. SW-161. Office of Solid Waste Management Programs. 1975. Pages 93-94.

CHAPTER XVII

RESOURCE RECOVERY SYSTEMS

Solid waste disposal can be viewed not only as a national problem, but as an opportunity for recovery and utilization of potentially valuable materials. This opportunity can be best exploited by developing economically viable resource recovery projects. Existing and emerging technology, combined with a new conservation awareness by the public, makes imperative the consideration of resource recovery as a part of municipal solid waste management systems.

In its broadest terms, resource recovery from municipal solid waste includes the conversion of solid waste components to energy, fuels, and other valuable products, as well as the recovery or salvage of existing materials. Energy recovery via incineration processes and conversion to fuels by pyrolysis have been discussed previously. This Chapter will be devoted to recovery of potentially valuable materials as a part of thermal processing systems.

Resource recovery may take place prior to thermal processing, or after the thermal processing step.

Resource Recovery Prior to Thermal Processing

Important materials which, in principle, can be salvaged from raw municipal solid waste include paper products, ferrous metals, non-ferrous metals, rags, glass, rubber, and plastics. The example in Table 79 for a mixed refuse shows that about 29 weight percent could be available for salvage, grossing $2.27 to $16.10 per metric ton of solid waste. Wide fluctuations in both salvage yield and prices necessitate detailed purity, yield, market, and cost studies for each project.

Historically, segregation at the source (e.g., curbside) or handsorting have been the principal approaches to salvage. These are still practiced to a minor extent. The volunteer recycling center is the most recent approach to salvage.

Sorting may be practiced for salvage purposes, or to segregate bulky materials, which are then shredded and mixed with the normal municipal solid waste for incineration, or disposed of in a landfill. Handsorting is unattractive because of the high cost of labor, and because of the modest degrees of separation which is practical, usually limited to bulky items. Separate collection of salvageable materials also tends to be costly, but this approach could become more practical in the future by the development of automated collection, and by increasing raw material prices.

Resource recovery prior to thermal processing can be justified not only by the value of the salvaged materials, but also by beneficial effects on the process. For example, removal of non-combustibles such as glass and metals

Table 79

POTENTIALLY SALVAGEABLE MATERIALS IN A MIXED MUNICIPAL REFUSE*

	Percent by Weight			
	Original Refuse	Potentially Salvageable	Commodity Value, $/MT Material	Potential Revenue $/MT Refuse
Paper and cardboard	33.0	15.0	5-50	0.75- 7.50
Glass	8.0	5.6	5-50	0.28- 2.80
Ferrous metals	7.6	6.8	5-50	0.34- 3.40
Nonferrous metals	0.6	0.6	150-400	0.90- 2.40
Plastics, leather, rubber, textiles, wood	6.4	1.0[‡]	-	-
Garbage and yard wastes	15.6	-	-	-
Miscellaneous (ash, dirt, etc.)	1.6	-	-	-
	73.0	29.0		$2.27-16.10/MT[#]
Moisture	27.0 100.0			($2.06-14.60/ST)

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* Based in part on data in reference 1.
‡ Potentially recoverable rags and plastics.
# Excludes possible credits for energy recovery from unsalvaged refuse.

will reduce the ash component of solid and liquid fuels produced during pyrolysis, or improve the incineration process by minimizing furnace damage and decreasing the quantity of solid residue. Removal of non-combustibles is a vital step in the preparation of combustible refuse for use as a fuel component in combination fossil fuel/prepared refuse steam boilers.

Two primary steps are required to practice the type of resource recovery technology now becoming available. The first is size reduction to allow physically freeing the various types of materials present from each other. Thus, size reduction usually precedes the second step, which is physical separation based on utilizing property differences of the materials present. Each of these steps will be discussed in more detail, followed by a discussion of commercially available resource recovery systems.

Size Reduction

The size reduction of municipal solid waste has been variously called shredding, milling, pulverizing, grinding, and comminution, even though only the last term can be considered truly generic. The other terms are more or less related to the type of equipment used. In this publication, the term shredder will be used as a general term for equipment designed to reduce the size of municipal solid waste, except where wet pulpers are used.

There may be as many as 70 suppliers of equipment with the potential for use in municipal waste size reduction.[2,3,6] The many kinds of equipment available are summarized in Table 80. The most common types now in use are the hammermills, and rotary ring grinders, but such classifications encompass many possible variations. For example, hammermills may be vertical or horizontal; they may use swing hammers, rigid hammers, and even shredding members; or they may differ in the design of reject systems.

The first stage of size reduction is usually designed to produce material nominally in the 5 to 25 centimeter (2 to 10 inch) range. Ballistic separation of metals may be an integral part of the first stage. A second stage, where required, reduces the size to that required for the process used, or for separation. Classification may be practiced between size reduction stages. A 50 ton per hour shredder will usually require a motor in the 500 to 1000 horsepower range.

Well designed primary size reduction equipment should be able to handle most objects found in unsorted municipal waste, including, for example, home appliances, storage drums, solid wood, and even tires on wheels; but hardened steel objects, and flammable and explosive materials can cause severe wear or damage. Other materials, such as rugs, mattresses, wire, or plastic sheets and milk bottles, sometimes cause operability problems. Collection restrictions, presorting, and prescreening can be helpful in a size reduction system, but troublesome materials are difficult to eliminate entirely. Actual tests should be carried out wherever possible before final equipment selection.

In addition to capital and operating costs, major considerations in the choice of size reduction equipment are durability, reliability, composition of feed, and suitability for the particular separation process contemplated. For

Table 80

CURRENT SIZE-REDUCTION EQUIPMENT AND POTENTIAL APPLICATIONS TO MUNICIPAL SOLID WASTE[a]

Basic types	Variations	Potential application to municipal solid waste
Crushers	Impact	Direct application as a form of hammermill.
	Jaw, roll, and gyrating	As a primary or parallel operation on brittle or friable material.
Cage disintegrators	Multi-cage or single-cage	As a parallel operation on brittle or friable material.
Shears	Multi-blade or single-blade	As a primary operation on wood or ductile materials.
Shredders, cutters, and chippers.	Pierce-and-tear type	Direct as hammermill with meshing shredding members, or parallel operation on paper and boxboard.
	Cutting type	Parallel on yard waste, paper, boxboard, wood, or plastics.
Rasp mills and drum pulverizers		Direct on moistened municipal solid waste; also as bulky item sorter for parallel line operations.
Disk mills	Single or multiple disk	Parallel operation on certain municipal solid waste fractions for special recovery treatment.
Wet pulpers	Single or multiple disk	Second operation on pulpable material.
Hammermills		Direct application or in tandem with other types.

example, a wet size reduction system would not be used with a dry separator, nor would a disintegrator producing primarily very fine particles be used with an air classifier. Wear, maintenance, and power input are other major considerations in the choice of size reduction equipment.

Size reduction can be practiced either on the entire waste stream prior to resource recovery, or simply as a method for reducing the size of bulky waste to allow handling in the thermal processing system.

Physical Separation

A thorough investigation into unit processes available for solid waste separation is provided in a 1971 U.S. Environmental Protection Agency report.[3] This report and more recent literature[4,5] discuss the techniques shown in Table 81. However, since solid waste separation is a rapidly evolving technology, the state-of-the-art must be carefully determined at the time of process selection. A few of the more advanced techniques will be described here.

Air Classification. Development studies in recent years have shown the feasibility of air classifying shredded municipal refuse to remove metal, glass, rocks, rubber, and wood.[6] As a result, air classification has been incorporated as a primary separation step into several municipal solid waste thermal processing systems, including the preparation of refuse for combined prepared refuse/fossil fuel combustion in steam boilers, for pyrolysis, and for fluidized bed combustion.

In a vertical air classifier, air is drawn upward through a vertical column at a predetermined velocity, while the shredded solids are fed to the top or to an intermediate point. The solid particles are fractionated according to density, size, and shape. The particles whose properties are such that they cannot be transported by the airstream move countercurrently to the stream, and are discharged at the bottom of the column. The transported particles move with the airstream through a blower and cyclone separator for recovery. In some cases, multiple classifiers in series can be used to separate several different products. Figure 60 is a schematic flow diagram showing one possible arrangement for such a system, while Figure 61 shows a cross section of an air classifier. A supplier's specification for a 45.4 metric ton per hour classifier is provided in Table 82, and an analysis of an air classified light fraction is provided in Table 83.

Ferromagnetic Separation. Removal of ferrous metals magnetically can be practiced prior to air classification, after air classification, or both. As will be discussed later, when resource recovery is not practiced prior to incineration, ferrous metals are sometimes recovered from incinerator residue. Removing ferrous metals from municipal solid wastes is basically rather simple, but problems arise from contamination of the recovered metal with refuse entrapped by the metal as it is attracted to the magnetic separator.

Table 61

UNIT PROCESSES FOR SOLID WASTE SEPARATION[2,4,5]

	Potential Municipal Solid Waste Application
Magnetic Separation	Magnetic materials (iron)
Inertial Separation Ballistic Secator Inclined Conveyor	Differences in size, density, elastic properties (depending on type)
Eddy-Current Separation	Conductive non-magnetic materials (copper, aluminum, zinc)
Electrostatic Separation	Aluminum from glass; plastics, paper[19]
Size Classification Vibrating Screens Spiral Classifiers	Preparation for further processing or rough cut separations
Air Classification Vertical Chute Zig-Zag Flow Classifier Horizontal Chute Vibrating Elutriator	Light material, such as paper, from heavier materials
Gravity Separation Dense Media Stoners Tabling Jigging Osborne Dry Separator Fluidized Bed Separator Rising Current Separator	Glass from metals, paper from other materials, and other separations based on density difference
Optical Sorting	Dirt from glass, separation of colored glass
Sweating	Melting to separate metals (e.g., lead and zinc from aluminum)
Flotation	Air bubbles in liquid used to separate materials with differing affinities for air and fluids used
Cryogenic Separation	Difference between materials in tendency to become brittle at low temperature (e.g. liquid nitrogen)

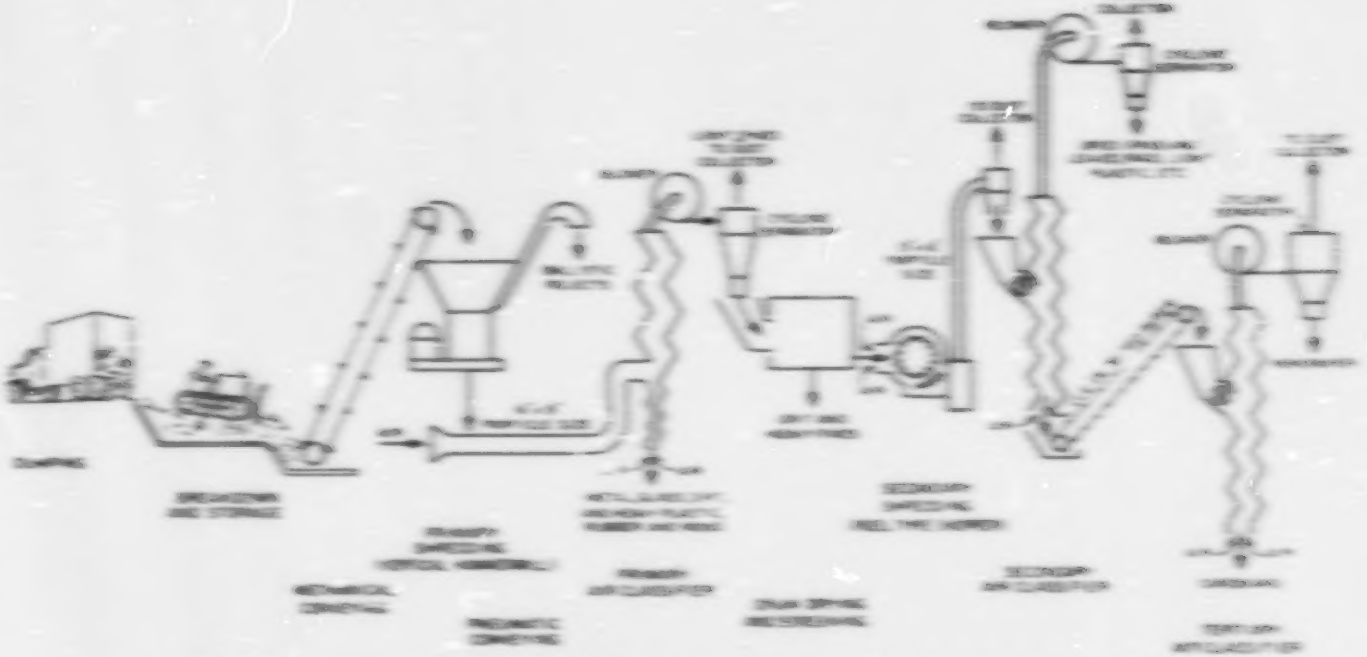

DUMPING
BREAKDOWN AND STORAGE
MECHANICAL CONVEYING
PRIMARY SHREDDING (VERTICAL HAMMERMILL)
PNEUMATIC CONVEYING
PRIMARY AIR CLASSIFIER
CYCLONE SEPARATOR
BLOWER
DRUM DRYING AND DESTONING
SECONDARY SHREDDING
SECONDARY AIR CLASSIFIER
TERTIARY AIR CLASSIFIER
CARDBOARD

Figure 1. [illegible]

FIGURE 62. AIR CLASSIFICATION OF SOLID WASTE

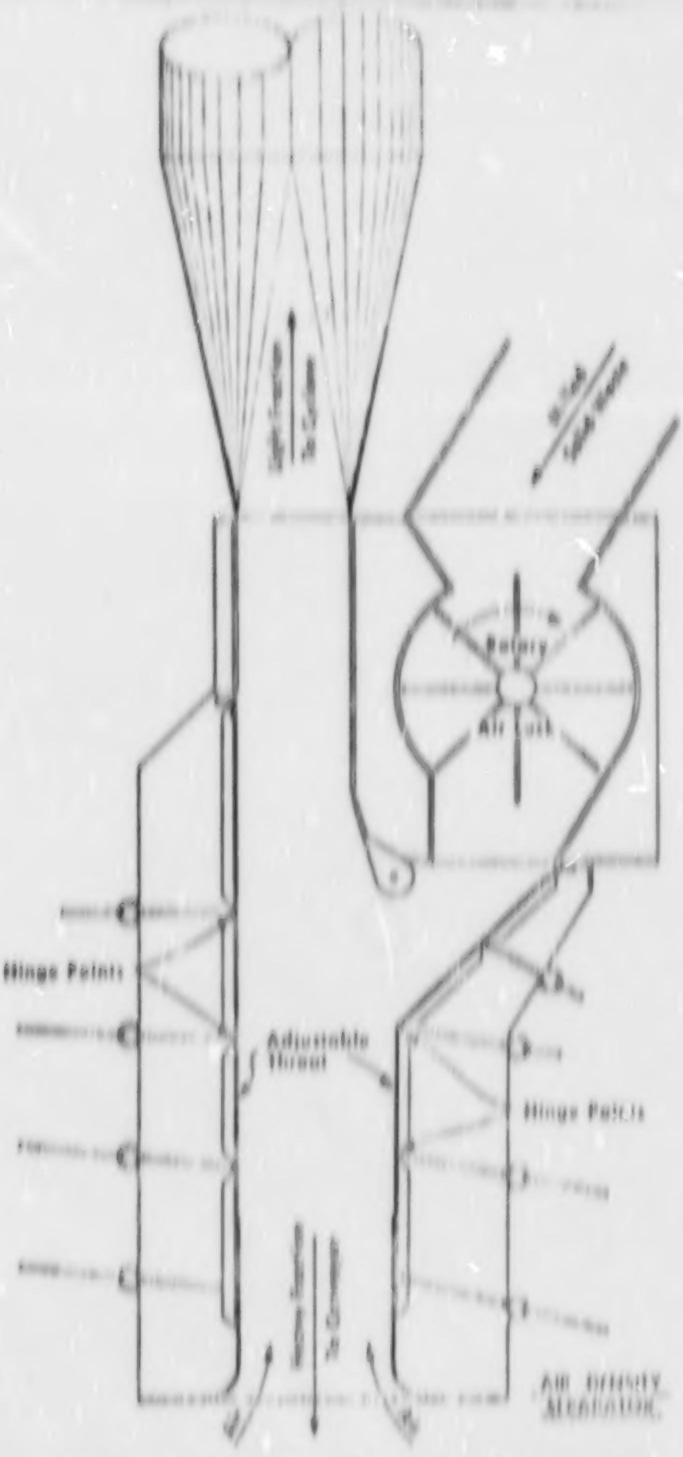

Rotary
Air Lock
Hinge Points
Adjustable Throat
Hinge Points
AIR DENSITY SEPARATOR

FIGURE 61. CROSS SECTION OF AN AIR CLASSIFIER[35]

Table 82

SPECIFICATION FOR AN AIR CLASSIFIER[a]

Feed: Milled residential, industrial, commercial solid waste
Particle size - 95% less than 20.23 cm. (8 in.)
- 99% less than 30.48 cm. (12 in.)
Moisture - 0-40% by weight
Density - 0.064 to 0.321 grams/cc (4-20 lbs/ft^3) loose

Envelope Dimensions (includes conveyors, blower, stands, etc.): 15.24 meters long by 15.24 meters wide x 12.19 meters high (50 x 50 x 40 ft.)

Weight Installed: 54.4 metric tons (60 short tons)

Electrical Requirements: 440 Volts -3 Phase -60 Hz

Total Installed Horsepower: 100-200

Nominal Performance:
Capacity - 41 to 54 metric tons per hr. (45-60 short tons/hr.)
Light Product (80-90 weight %) - Less than 10 weight % inerts (fine glass, sand)
Heavy Product (10-20 weight %) - Less than 5 weight % fibrous material
- 98% of the ferrous metals
- 80% of the aluminum
- 98% of the other metals
- 80% of the glass

Table 83

AIR CLASSIFIED REFUSE ANALYSES LIGHT FRACTION

194 samples taken November 9, 1973 through March 28, 1974[25]

	As Received Basis, Wt. %						
	Moisture	Ash	Sulfur	Chlorides Total	Chlorides NaCl	Cal/g	(Btu/lb)*
Average	30.3	16.8	0.10	0.41	0.33	2768	(4983)
Maximum	66.3	31.3	0.28	0.94	0.59	4218	(7593)
Minimum	11.1	7.6	0.04	0.14	0.11	1274	(2293)

Ash Analysis, Wt. %

	Average	Maximum	Minimum
P_2O_5	1.43	2.04	0.99
SiO_2	49.90	58.10	39.90
Al_2O_3	11.30	26.90	6.10
TiO_2	0.87	1.52	0.07
Fe_2O_3	7.89	22.19	3.03
CaO	12.21	15.80	8.51
MgO	1.29	7.37	0.22
SO_3	1.48	3.75	0.54
K_2O	1.57	2.91	0.92
Na_2O	8.87	19.20	3.11
SnO_2	0.05	0.10	0.02
CuO	0.32	1.74	0.08
ZnO	0.41	2.26	0.09
PbO	0.19	0.73	0.04

* higher heating value

The magnets used can be of a permanent type, or electromagnets. Direct current for the electromagnets normally required purchase of a rectifier. Alternating current is required for belt drives. When electromagnets are used, designs must allow for lower magnetic strength at operating temperatures as compared to cold startup temperature.

Rotating drum and suspended magnets have been used for primary separation. These and pulley type magnetic separators can be used after classification.[6,7] Although magnetic separators have been widely used in industry, design changes have been necessary to adapt these to processing of municipal solid waste. For example, multiple magnets in a suspended separator with a moving belt and modified drums have been developed to separate non-magnetic entrapped materials by successive attraction and release of the ferrous metals.

Nonferrous Metal Separation. A promising advance in this field is the development of eddy-current techniques for the separation of conducting non-magnetic materials from municipal solid waste which has been pre-processed by shredding, classifying, and ferrous metal removal.[7] The trash-metal mix from the pre-processing steps is conveyed into a polyphase alternating current electromagnetic field which induces electrical currents in conducting materials, such as aluminum, generating in turn magnetic flux opposite in direction to the initially imposed flux. The resulting repulsive force sweeps aluminum can stock laterally off the belt for collection.

A single aluminum separator module is designed to handle approximately 1.3 to 2.3 metric tons per hour of trash-metal mix recovered from about 9 metric tons per hour (10 short tons/hr) of shredded waste. Therefore, a 36 metric ton per hour (960 short tons/day) thermal processing plant would require a splitter and at least four modules. Other limitations of this approach include the necessity for a relatively high speed belt to allow spreading out the feed, reducing the probability of extraneous material being swept off the belt with the aluminum stock; the necessity for careful shredding both to avoid too fine shredding which can cause aluminum flaking and loss in pre-processing steps, and too coarse shredding which can result in poor air classification increasing the contamination and quantity of the trash-metal fraction; and the potentially increased contamination level of recovered aluminum when the fraction of aluminum in the shredded waste is low.

System specifications for a four module aluminum separator are shown in Table B4. A second stage separator is under development to recover a mixed product containing the remaining aluminum, and other metallics such as copper, zinc, stainless steel, and brass.

The heavy fraction from air classification can also be processed with a series of screens and sink-float (dense media) devices to separate individual metals. This approach is under development.

Wet Pulping. The organic and friable fractions of solid wastes can be converted into a water slurry in equipment known as a Hydrapulper.[10] In this pulping process, after separation of non-suitable feed materials such as tires,

Table 84

SPECIFICATION FOR A DRY ALUMINUM SEPARATION TECHNIQUE[7,8]

Modules: Four (for a 36 MT/hr thermal processing plant)

Feed: Dense fraction of milled classified residential, commercial solid waste, less ferrous metals
Particle size - 95% less than 15.24 cm. (6 in.)
Aluminum size - 90% greater than 2.54 cm. (1 in.)
Moisture - No limitations
Density - Greater than 0.64 grams/cc (40 lbs/ft³)
Shape - No limitations

Envelope Dimensions (includes conveyors, screen, separators): 12.2 meters long by 6.1 meters wide by 3.05 meters high (40 ft x 20 ft x 10 ft)

Electrical Requirements: 440 Volts - 3 Phase - 60 Hz

Total Installed Horsepower: 75 (equivalent)

Efficiency: 60-80% recovery of can stock material (based on aluminum in dense fraction); about 50% of total aluminum in solid waste

Aluminum Analyses (based on pilot plant samples):

	Chemical Analysis, weight %		
Element	Sample I	Sample II	Alcoa Grade 1
Si	0.28%	0.26%	0.3%
Fe	0.43	0.41	0.5
Cu	0.14	0.16	0.25
Mn	0.84	0.83	1.25
Mg	0.96	0.99	2.0
Cr	0.02	0.02	0.2
Ni	0.00	0.00	0.2
Zn	0.05	0.45	0.5
Ti	0.02	0.02	-
V	0.01	0.01	-
Pb	0.00	0.00	0.1
Sn	0.00	0.00	0.1
Bi	0.00	0.00	0.1

Hand Picked Analysis, weight %

Pieces of Cans or Containers	91.75
Heavy Material	7.5
Foil	0.1
Dirt	0.7
	100.0

large appliances, and building demolition wastes, water is added to the solid waste in a large mixing vessel containing a high speed cutting rotor, similar to a Waring blender. Non-pulpable material, such as metal cans and stones, are ejected through an opening in the side of the mixing vessel. The slurry, containing about 3 to 4 weight percent solids, is removed through a perforated plate at the bottom to a liquid cyclone and other equipment for subsequent recovery and separation of metals, glass, and organics. Wet pulping in effect serves both as a size reduction method and as a first step in a series of physical separations.

Usable long paper fibers can be recovered from the slurry for sale as a low-grade paper fiber, leaving an organic residue suitable for thermal processing, or the entire organic fraction can be recovered from thermal processing without separating the paper fibers. A 5 to 7 metric ton per hour (150 short tons/day) demonstration has been conducted.[10] The Hydrapulper in this operation was 3.66 meters (12 feet) in diameter and equipped with a 300 horsepower motor.

Glass Separation. The recovery of mixed glass in a resource recovery operation will normally be from a secondary or tertiary separation step, after separation of light materials, such as paper and metals. The methods used will vary with the overall scheme, involving processes such as air classification, dense media separation, froth flotation, and water elutriation. However, the mixed glass product has limited value unless it is color sorted and free of contaminants.[11] Since a market does exist for pure color sorted glass cullet, there is considerable incentive for automatic color sorting to separate flint (clear), amber, and green fractions. This technology is under development.[12,13]

In the Sortex optical separator, a continuous stream of individual particles are dropped through an optical box, containing three photocell assemblies set at 120° intervals and suitable illumination sources. Opposite each photocell head is a background with variable shades of color. Each particle passes through the viewing area and, if there is a change in its reflectivity with respect to the background standard, either lighter or darker as desired, a blast of compressed air is triggered to deflect the offcolor particle from the main stream. Two optical separators in series will first separate flint (clear) from colored glass, and then separate the colored glass into amber and green.[14]

Conveying Systems

Conveyor performance plays a major role in determining the reliability of resource recovery systems. Various conveyors used are called infeed conveyors, for feeding shredders; transfer conveyors, for transferring shredded material from the shredder discharge to a discharge conveyor; discharge conveyors, for discharging to a storage area or the next processing step; and other conveyors used for magnetic separation, changes in direction, etc.

Belt conveyors are easily maintained and are usually the least expensive of the conveyor types available, but are subject to failure by impact of sharp objects fed onto the belt from trucks, cranes, or other feeders. Their minimum speed of about 24 meters per minute (80 ft./min.) for good tracking is generally too fast for feeding a shredder. On the other hand, speeds greater than 24 meters per minute may cause paper and other light materials to float. In addition, angles greater than 20° without cleating are not recommended. Therefore, the best uses for belt conveyors in resource recovery systems are for conveying heavy materials at high speeds over level areas, and for use with magnetic separators where ordinary steel conveyors interfere with magnetic operation.

Apron conveyors are preferred for infeeding and transfer conveyors even though capital cost, horsepower, and maintenance are greater than for other types of conveyors.[15] For infeeding, these conveyors are typically 1.2 to 1.8 meters (48 to 72 in.) wide and travel 1.5 to 7.6 meters per minute (5 to 25 ft./min.) with a variable speed drive. They can be inclined to approximately 35° with 10 cm. (4 in.) flights welded to the pans. Compression feeders and leveling conveyors are often used with apron conveyors for infeeding to shredders. Special attention must be paid to the details of conveyor construction to insure proper operation, rugged construction, and ease of maintenance.[15] A typical shredder installation with conveyors is shown in Figure 62.

Integrated Resource Recovery Systems

Although important advances have been made in recent years, no complete resource recovery system can be categorized as fully developed for widespread application. A summary of available systems which can provide feed for thermal processing is provided in Table 85. Flow diagrams for some of these systems are provided as Figures 63 to 69.

Resource Recovery After Thermal Processing

Each available thermal process produces at least one solid residual material with limited potential value. Typical incinerator residues, shown in Tables 86 to 88, contain large amounts of glass and ferrous metal. Resource recovery prior to incineration, not now practiced to any significant degree, would obviously reduce the total amount of residue considerably and change its nature. The exact effect would depend upon: whether only ferrous metal was recovered; whether both ferrous metal and glass were recovered; whether other materials such as nonferrous metals were recovered; and the efficiency of these recoveries. The separation and firing of a combustible fraction with coal in a conventional boiler leads to an ash, mixed with and essentially indistinguishable from the coal ash.

The residues from pyrolysis processes were discussed in the Pyrolysis Chapter. These may be high ash chars, with some potential value as a low grade fuel; and slag-like materials high in glass content, with some potential value as construction materials. Of the commercially available processes, only in the Landgard process is ferrous metal recovered after pyrolysis, and even there, plans to magnetically separate the solid waste feed will limit such recovery from the residue.

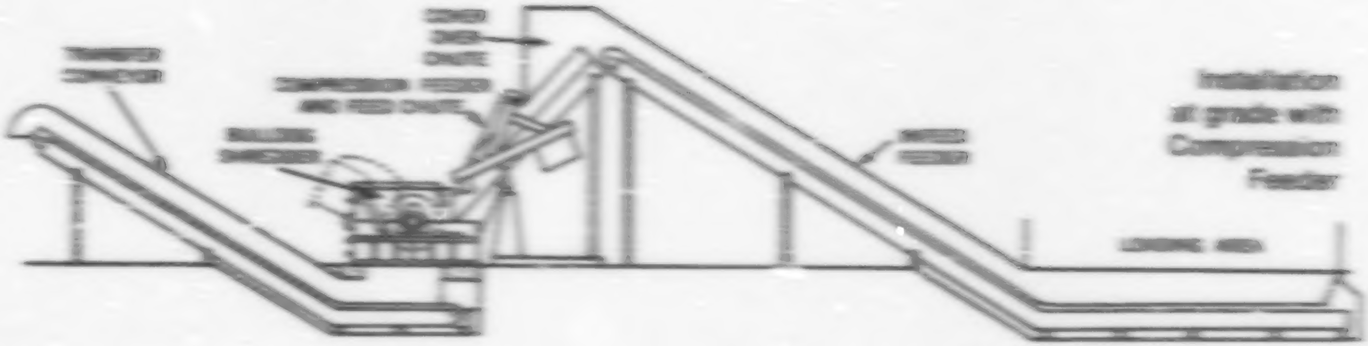

TRANSFER CONVEYOR
COMPRESSION FEEDER AND FEED CHUTE
Installation at grade with Compression Feeder
LOADING AREA

FIGURE 62. TYPICAL SHREDDING PLANT

Table 85

STATUS OF AVAILABLE INTEGRATED RESOURCE RECOVERY SYSTEMS

Name/Developers/Sponsors	Primary Products	Secondary Products	Development Status*
Horner and Shifrin; Union Electric Co.; City of St. Louis, Mo.*	Fuel, Ferrous Metal	Power from fuel in power plant	37 MT/hr (650 ST/D over 2 shifts) evaluation underway[22]
CPU-400, Combustion Power Co.*	Fuel, Ferrous Metal, Aluminum, Nonferrous Metal Mix, Dirty Glass, Trash	Power from fuel in high pressure fluidized bed and gas turbines	3 MT/hr. (80 ST/D) pilot plant evaluation-resource recovery promising/energy recovery problems to be solved[22]
Hydrasposal, Black Clawson Co.; Franklin, Ohio; Glass Container Manufacturers Institute*	Fuel, Paper Fiber, Ferrous Metal, Color Sorted Glass, Aluminum	Credit for sewage sludge disposed of in combustor	5.7 MT/hr (150 ST/D) evaluation underway[22]
Bureau of Mines*	Fuel, Ferrous Metal, Aluminum, Nonferrous Metal Mix, Sorted Glass	-	4.5 MT/hr. (5 ST/hr) pilot plant[23]
Occidental Research Corp.; County of San Diego; San Diego Gas & Electric Co.*	Pyrolysis Feed, Ferrous Metal, Mixed Glass, Residue	Pyrolytic oil, High Ash Char	Pilot plant operations—7.6 MT/hr. 200 ST/D plant under construction, to be completed in late 1976.
LANDGARD, Monsanto Enviro-Chem Systems, Inc.; City of Baltimore; State of Maryland*	Pyrolysis Feed, Ferrous Metal	Steam, Glassy Aggregate, Char Residue	37.8 MT/hr. (1000 ST/D) plant in shakedown in late 1975.
Hercules, Inc; State of Delaware*	Fuel, Ferrous Metal, Heavy	Power from fuel in power plant;	Plant to handle 18.9 MT/hr. (500 ST/D) municipal refuse plus

Table 85 (cont.)

Name/Developers/Sponsors	Primary Products	Secondary Products	Development Status*
	Residue, (from municipal refuse)	Pyrolysis of industrial waste with municipal residue to recover fuels, nonferrous metal, glass	Industrial waste and sewage sludge being designed[22]
Eco-Fuel, Combustion Equipment Assoc.	Fuel, Glass, Metals	-	45 MT/hr. (1200 ST/D) capacity plant in East Bridgewater, Mass.—performance unknown[22]
Gibbs, Hill, Durham & Richardson-Inc; City of Ames, Iowa	Fuel, Ferrous Metal, Aluminum, Nonferrous Metal Mix, Dirty Glass, Residue	Power from fuel (in municipally owned power plant)	7.9 MT/hr. (210 ST/D) of segregated waste[22-25] shakedown in late 1975.
National Center for Resource Recovery, Inc; City of New Orleans; Waste Management, Inc.	Fuel, Ferrous Metal, Aluminum, Nonferrous Metals, Sorted Glass	Fuel (light combustibles) may be landfilled initially	24.6 MT/hr. (650 ST/D). Scheduled for startup in summer 1976.
State of Connecticut; Occidental Research Corporation; Combustion Equipment Associates: American Metals Climax: SCA Services, Inc.	Fuel, Ferrous Metal, Aluminum, Glass, Residue	Power from fuels in power plants	Design of systems for Bridgeport, and New Britain/Hartford to total 136 MT/hr (3600 ST/D)—scheduled for operation by mid-1976[17]
Siva International Corp.	Fuel, Ferrous Metal, Residue	-	4.5 MT/hr. demonstration plant in Los Gatos, Calif.—to be expan[illegible] to 18 MT/hr—performance unknown; fuel pelletized[23]

Table 85 (cont.)

Name/Developers/Sponsors	Primary Products	Secondary Products	Development Status*
Americology, American Can Co.	Fuel, Ferrous Metal, Aluminum, Glass, Paper	Power from fuel in power plant	45.4 MT/hr. (1200 ST/D) plant being designed for Milwaukee, Wisc.[21]
Eastman Kodak	Fuel, Metal	Steam from incineration of fuel	11.3 MT/hr. (300 ST/D) plant operating in Rochester, N.Y.

* Indicates Federal support[22]

** MT = metric tons (2205 lbs), ST = short tons, D = day

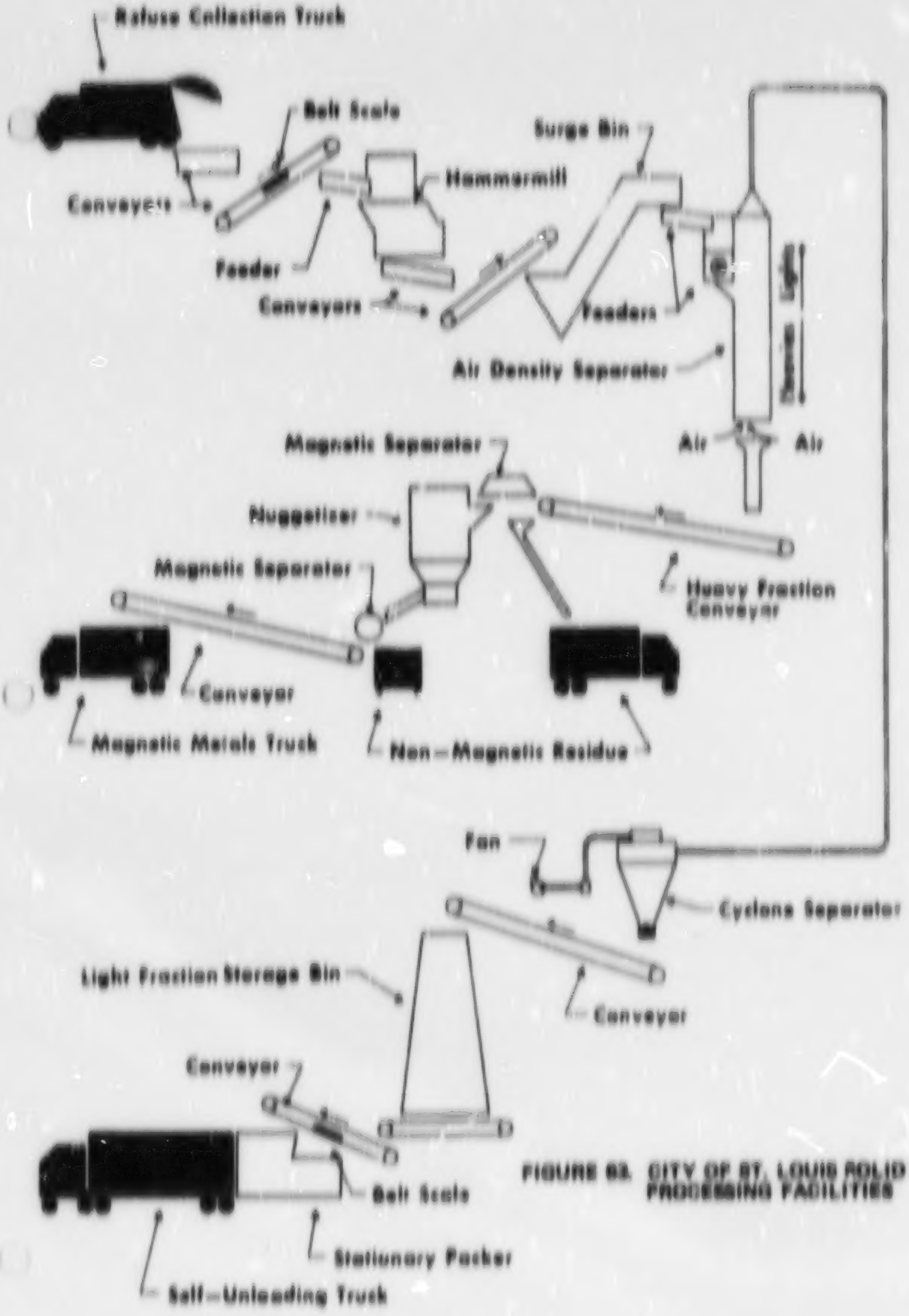

Refuse Collection Truck
Belt Scale
Conveyors
Feeder
Hammermill
Conveyors
Surge Bin
Feeders
Lights
Heavies
Air Density Separator
Air
Air
Magnetic Separator
Nuggetizer
Magnetic Separator
Heavy Fraction Conveyor
Conveyor
Magnetic Metals Truck
Non-Magnetic Residue
Fan
Cyclone Separator
Light Fraction Storage Bin
Conveyor
Conveyor
Belt Scale
Stationary Packer
Self-Unloading Truck

FIGURE 63. CITY OF ST. LOUIS SOLID WASTE PROCESSING FACILITIES

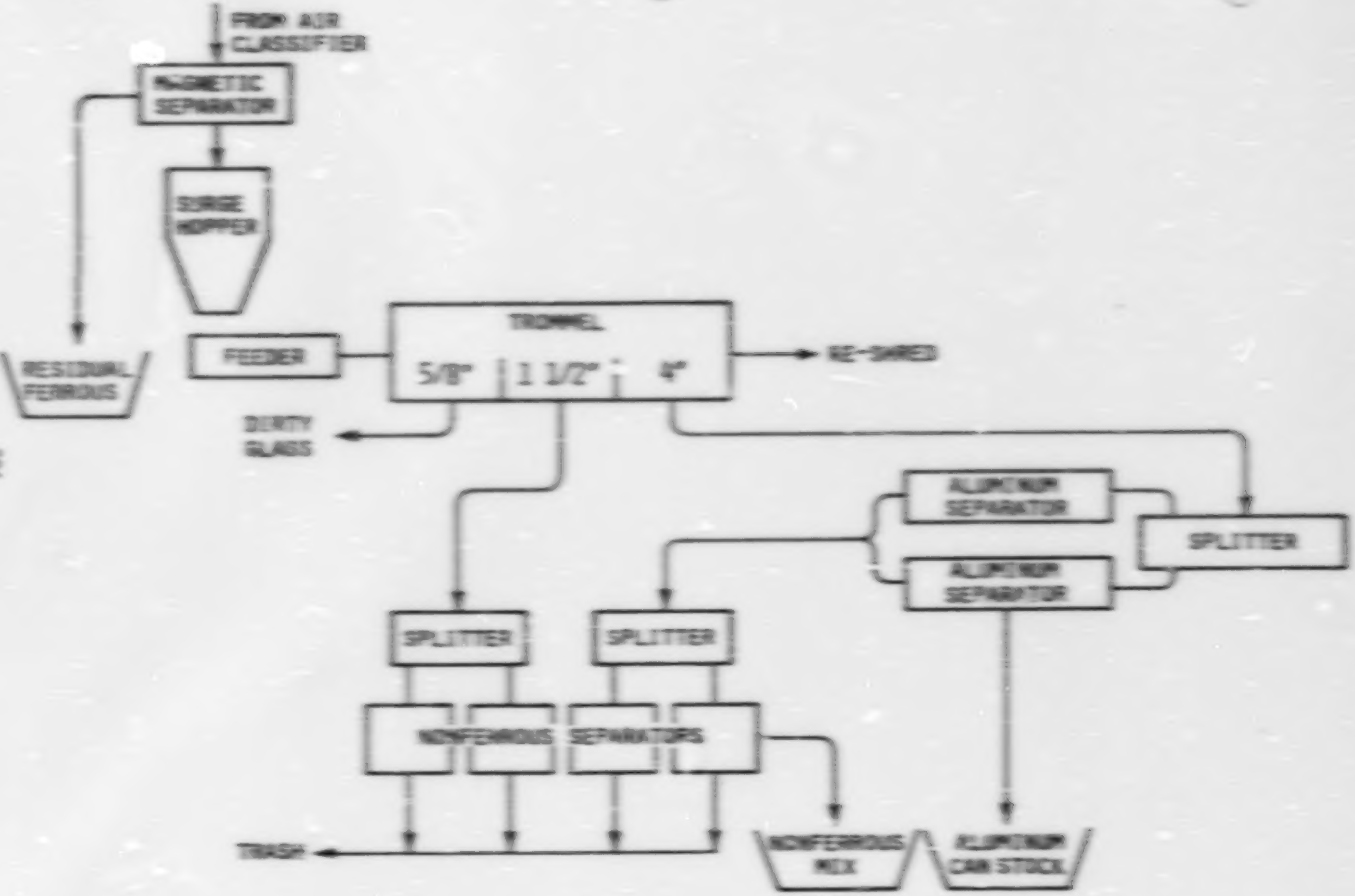

FROM AIR CLASSIFIER
MAGNETIC SEPARATOR
SURGE HOPPER
RESIDUAL FERROUS
FEEDER
TROMMEL
5/8"
1 1/2"
4"
RE-SHRED
DIRTY GLASS
ALUMINUM SEPARATOR
ALUMINUM SEPARATOR
SPLITTER
SPLITTER
SPLITTER
NONFERROUS SEPARATORS
TRASH
NONFERROUS MIX
ALUMINUM CAN STOCK

FIGURE 6A. CPU-400 MATERIAL RECOVERY SYSTEM

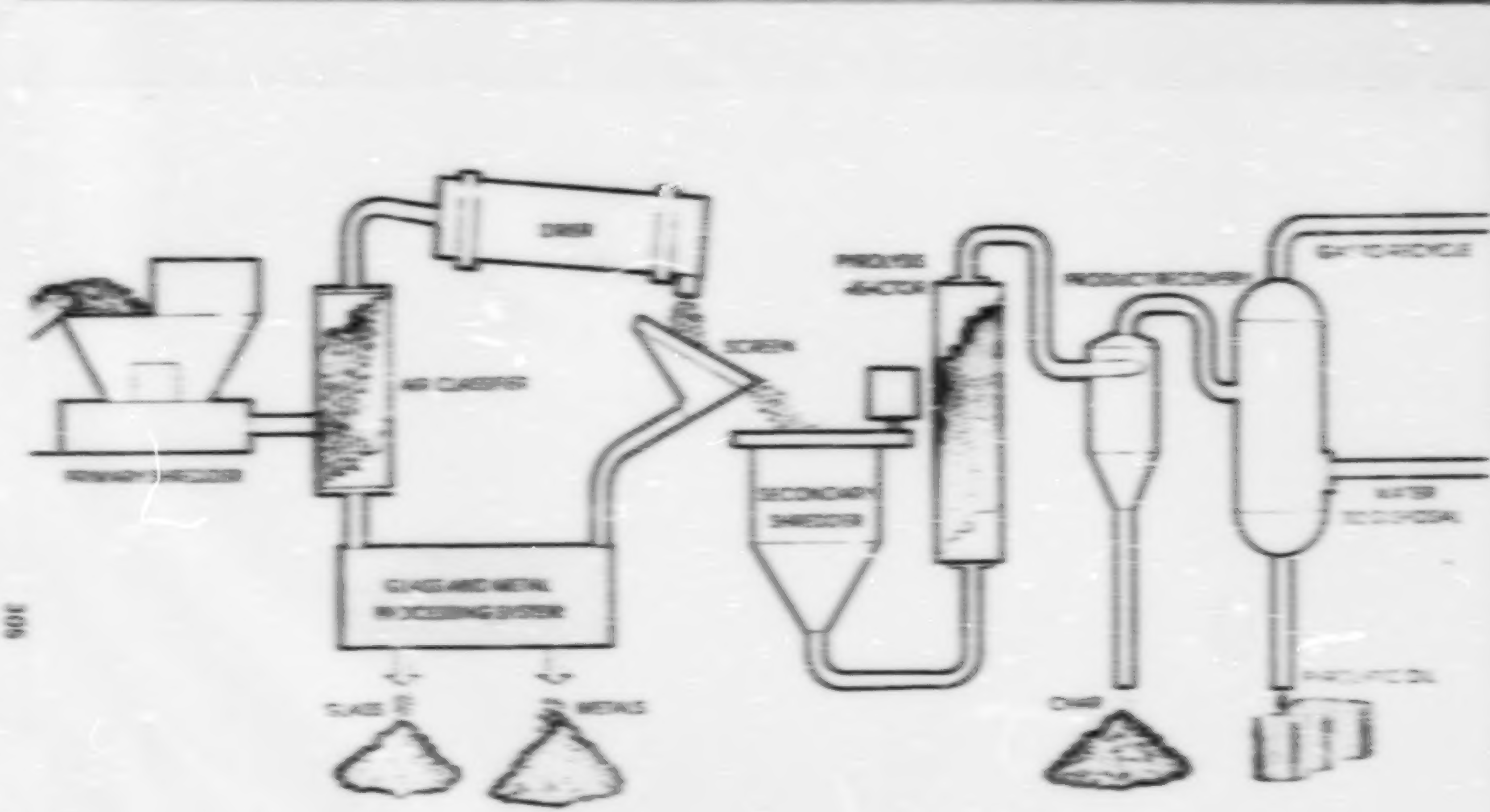
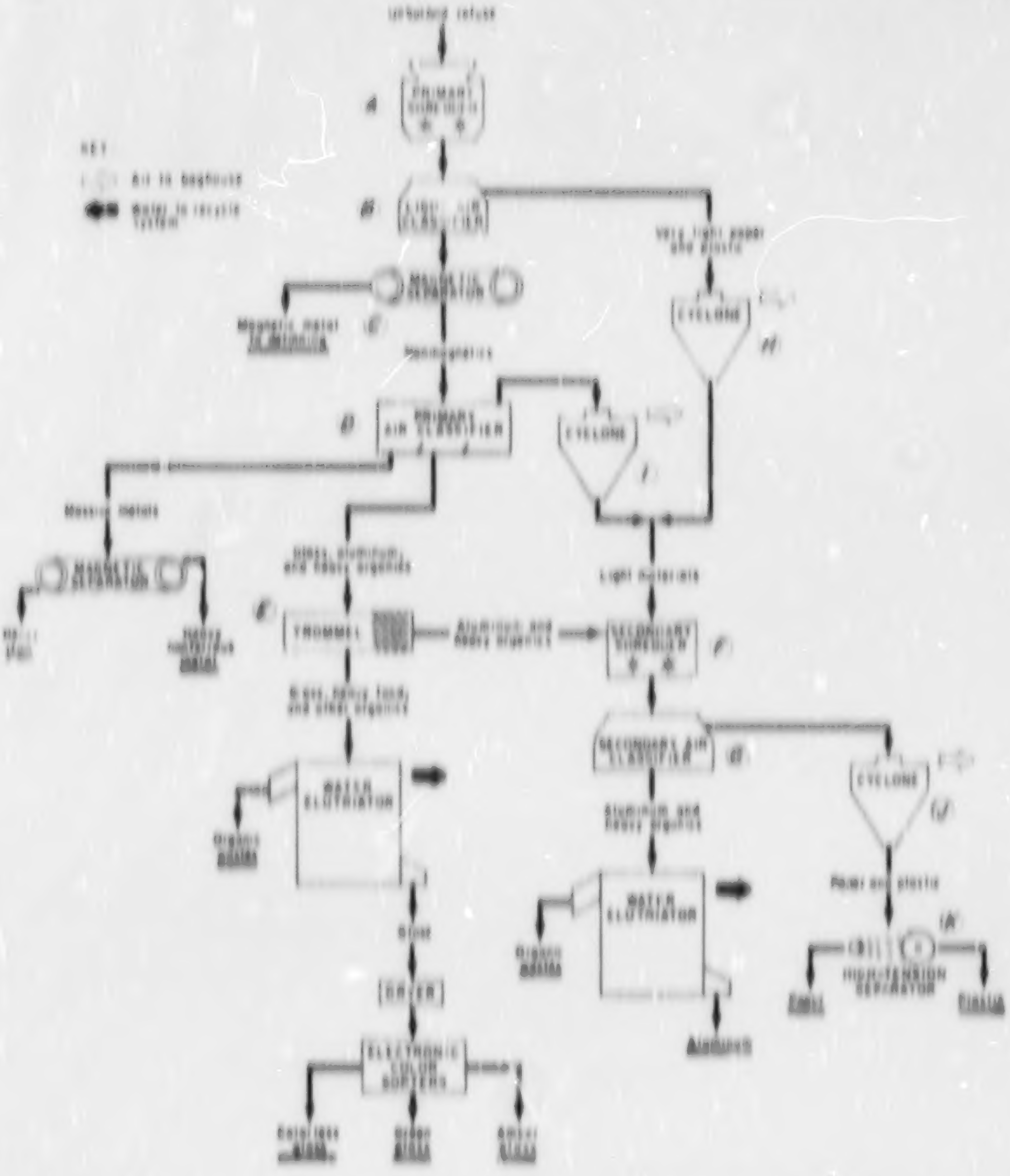

PRIMARY SHREDDER
AIR CLASSIFIER
DRYER
SCREEN
GLASS AND METAL
PROCESSING SYSTEM
GLASS
METALS
SECONDARY
SHREDDER
PYROLYSIS
REACTOR
PRODUCT RECOVERY
GAS TO RECYCLE
WATER
TO DISPOSAL
CHAR
PYROLYTIC OIL

FIGURE 65. OCCIDENTAL RESEARCH CORP. RESOURCE RECOVERY AND PYROLYSIS PROCESS



Unsorted refuse
A
PRIMARY SHREDDER
KEY
Air to baghouse
Water to recycle system
B
LIGHT AIR CLASSIFIER
Very light paper and plastic
MAGNETIC SEPARATOR
Magnetic metal to detinning
C
CYCLONE
H
Nonmagnetics
D
PRIMARY AIR CLASSIFIER
CYCLONE
I
Massive metals
MAGNETIC SEPARATOR
Steel
Heavy nonferrous metal
Glass, aluminum, and heavy organics
Light materials
E
TROMMEL
Aluminum and heavy organics
SECONDARY SHREDDER
F
Glass, heavy food, and other organics
SECONDARY AIR CLASSIFIER
G
CYCLONE
J
WATER ELUTRIATOR
Organic wastes
Aluminum and heavy organics
Paper and plastic
K
Glass
WATER ELUTRIATOR
Organic wastes
HIGH-TENSION SEPARATOR
Paper
Plastic
DRYER
Aluminum
ELECTRONIC COLOR SORTERS
Colorless glass
Green glass
Amber glass

FIGURE 66. BUREAU OF MINES RAW SOLID WASTE SEPARATION SYSTEM

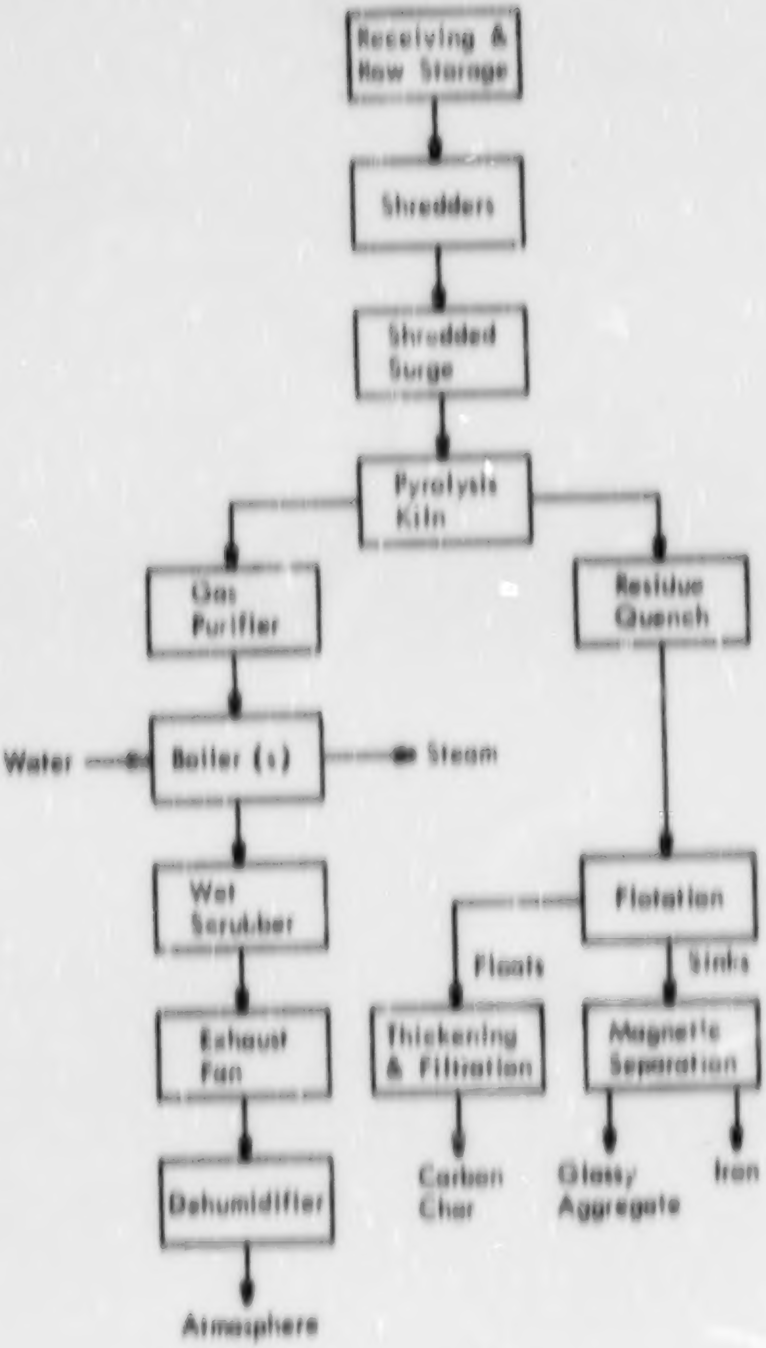

Receiving & Raw Storage
Shredders
Shredded Surge
Pyrolysis Kiln
Gas Purifier
Residue Quench
Water
Boiler (s)
Steam
Wet Scrubber
Flotation
Floats
Sinks
Exhaust Fan
Thickening & Filtration
Magnetic Separation
Dehumidifier
Carbon Char
Glassy Aggregate
Iron
Atmosphere

FIGURE 67. LANDGARD RESOURCE RECOVERY AND PYROLYSIS SYSTEM

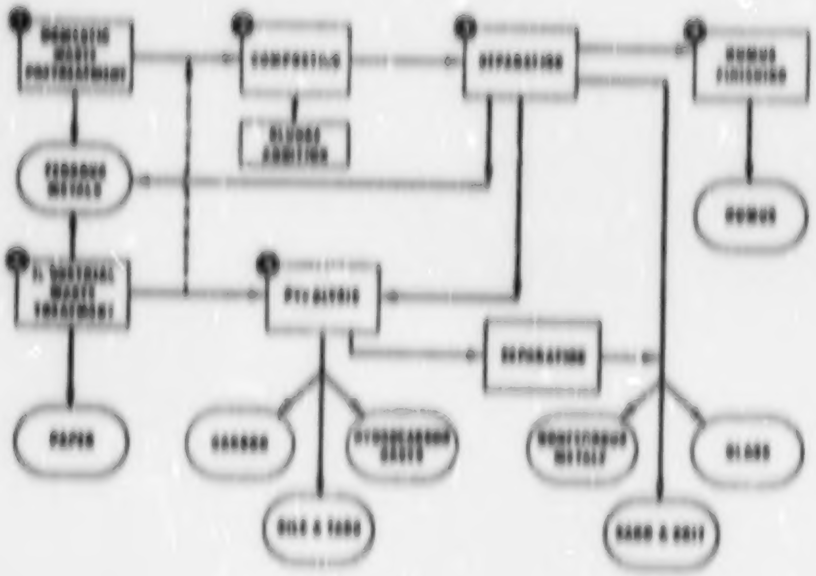
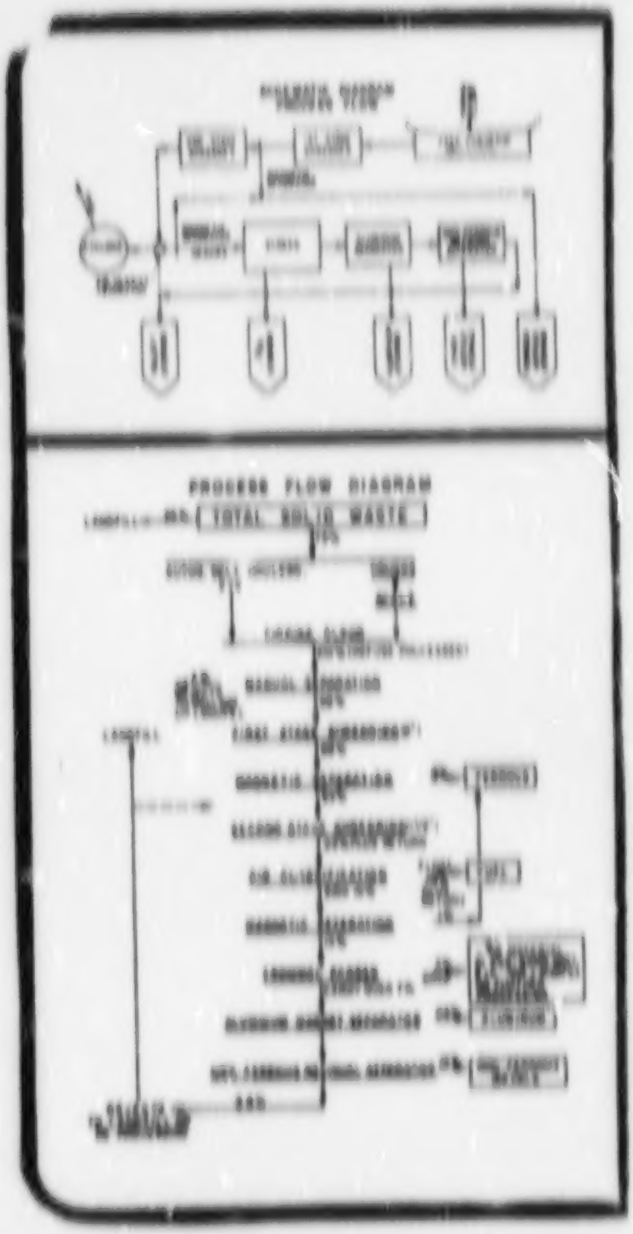

DOMESTIC WASTE PRETREATMENT
COMPOSTING
SEPARATION
HUMUS FINISHING
SLUDGE ADDITION
FERROUS METALS
HUMUS
INDUSTRIAL WASTE TREATMENT
PYROLYSIS
SEPARATION
PAPER
CARBON
HYDROCARBON GASES
NONFERROUS METALS
GLASS
OIL & TARS
SAND & GRIT

FIGURE 66. HERCULES RESOURCE RECOVERY SYSTEM



PROCESS FLOW DIAGRAM
TOTAL SOLID WASTE

FIGURE 69. AMES RESOURCE RECOVERY SYSTEM

Table 86

COMPOSITION OF GRATE-TYPE INCINERATOR RESIDUES[a]

Component	Average percentage*
Glass	44.1
Tin cans	17.0
Mill scale and small iron	6.0
Iron wire	0.7
Massive iron	3.5
Nonferrous metals	1.4
Stone and bricks	1.3
Ceramics	0.9
Unburned paper and chemical	8.3
Partially burned organics	0.7
Ash	15.4
Total	100.3

Table 87

COMPOSITION OF ROTARY-KILN INCINERATOR RESIDUES[a]

Component	Average percentage*
Fines, minus 8-mesh (ash, slag, glass)†	36.8
Glass and slag, plus 8-mesh#	21.2
Shredded tin cans	19.3
Mill scale and small iron	10.7
Nonmetallics from shredded tin cans	6.5
Charcoal	3.4
Massive iron	1.9
Iron wire	0.5
Ceramics	0.2
Handpicked nonferrous metals	0.1
Total	99.6

---

* Dry weight basis.

† Of the total weight of this fraction, 1.8 percent is recoverable nonferrous metal.

# Of the total weight of this fraction, 1.4 percent is recoverable nonferrous metal.

Table 48

ANALYSIS OF INCINERATOR RESIDUE[24]

Dry Basis

Component	Weight Percent
Wire and large iron	3.0
Tin cans	13.6
Small ferrous metal	13.9
Nonferrous metal	2.8
Glass	49.6
Ash	17.1
TOTAL	100.0

Current Incinerator Residue Salvage

The only significant salvage practiced on incinerator residue is ferrous metal recovery. Even this practice is limited to not more than 10 to 20 incinerators in the United States. Ferrous metal, primarily cans, is recovered from residue either magnetically, or by the use of revolving cylindrical screens called trommels. The cans are retained by the trommel, while most of residue passes through for landfill disposal. Ferrous metal recovered by either method may be washed and shredded in the incineration plant, or by the purchaser.

Most of the recovered ferrous metals must be shipped to the western part of the United States for use in copper precipitation. The remaining recovered ferrous metal is either used directly in steelmaking, or first detinned and then used for steelmaking.

Emerging Incinerator Residue Salvage Technology

Ferrous metals are valuable and relatively easy to recover from incinerator residues, but glass and nonferrous metals in the residue are also potentially valuable. For this reason, the U.S. Bureau of Mines has piloted a complete resource recovery system for incinerator residue. A full-size processing plant designed by the Raytheon Company based on Bureau of Mines data, and capable of handling 227 metric tons of incinerator residue per 8 hours, is being built in Lowell, Massachusetts with Federal assistance (cancelled July 1975).[12] The processing scheme will be similar to that shown in Figure 70, producing the materials shown in Table 69.

Markets for Recovered Materials

The ultimate success of any resource recovery system hinges both on the availability of suitable markets and on the availability of technology and operating skill to produce products meeting the specifications required in the marketplace. The commitment of capital for resource recovery facilities must be preceded by identification, understanding, and security of markets. A few of the fundamental considerations follow.

Fuel

As previously discussed, the marketing problems which exist for 100 percent solid waste firing in a steam producing municipal incinerator are those of being reasonably close to the demand for steam or electrical power, and of matching supply with a varying demand. On the other hand, the preparation of combustible refuse as a fuel, for firing with fossil fuels in existing utility system boilers, introduces normal product marketing problems such as quality, quantity, shipping distance, storage capacity, and competition with conventional fuels.

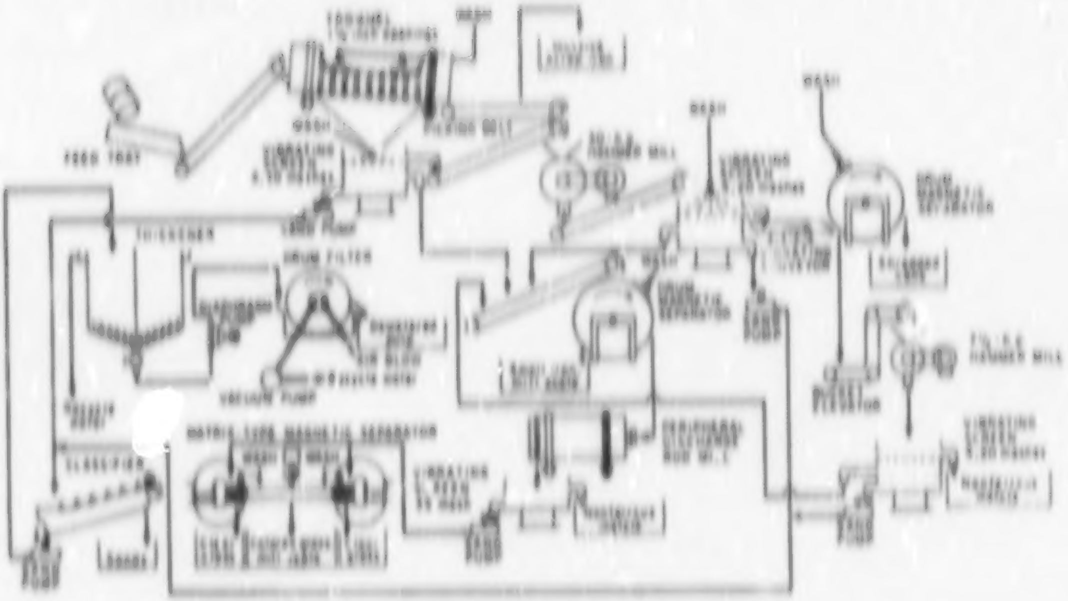

FEED TRAY
WASH
THICKENER
DRUM FILTER
VACUUM PUMP
CLASSIFIER
MATRIX TYPE MAGNETIC SEPARATOR
HAMMER MILL
VIBRATING SCREEN
PUMP

FIGURE 70. BUREAU OF MINES INCINERATOR RESIDUE RECOVERY SYSTEM[1]

Table 89

EXPECTED PRODUCTS FROM THE LOWELL INCINERATOR RESIDUE RESOURCE RECOVERY PROJECT (CANCELLED JULY 1970)

	Weight Percent of the Residue
High Value Products	
Aluminum	1.5
Zinc-Copper	1.0
Ferrous Products	30.5
Colorless Glass	20.8
Medium Value Products	
Mixed Color Glass	10.2
Slag	14.0
Sand	17.0
Waste Products	
Unburned Organics	1.4
Filter Cake	3.6
	100.0

The experience already accumulated on preparing refuse derived fuel from solid waste and firing this fuel with coal in an existing boiler lends confidence to such projects. However, as other similar projects are undertaken, great care must be observed to avoid problems which could arise due to difference in the physical and chemical properties of the fuel, and due to differences in steam boiler design. For example, chemical properties of the fuel might vary with classifier operation, raising questions about corrosion, slagging, and air pollution control in the boiler. Besides careful choice of processing equipment, the best means for avoiding such problems are careful analysis of raw refuse, prepared fuel, and other materials, and co-operative testing with potential customers.

It is anticipated that carefully prepared fuel from municipal solid waste should eventually approach the value of coal on a net heating value basis, though more complex evaluation procedures have been developed.[26] The calculation of value per ton of fuel is illustrated in Table 90. Although all characteristics of the fuel (such as physical form, sulfur, ash, and chlorine contents and ash fusion point) may play a role in determining its price, the heating value and shipping distance are overriding factors, assuming the basic acceptability of the fuel for its intended use.

A full understanding of the intended use is vital in determining its value to the customer. For example, the low sulfur content of prepared refuse fuel is a credit in boilers having difficulty meeting sulfur oxide emission standards, but may be a liability in boilers already burning low sulfur coal where low sulfur levels can lead to insufficient natural sulfur trioxide gas conditioning required for adequate electrostatic precipitator performance. In other applications the ash content may be critical, where the relatively high ash per unit of heating value in fuels derived from solid waste may increase particulate emissions, or overload existing ash handling systems.

Paper Fiber

In some installations the recovery of paper fiber may be justified even at the expense of feed to the thermal processing facilities. For example, paper fiber recovered from an existing resource recovery system was reportedly sold in the $27 to $72/MG ($26 to $65/ST) range,[27] certainly competitive with fuel use. Therefore, it is advisable to investigate the cost of paper fiber recovery and possible markets to determine whether such recovery is justified.

Ferrous Metals

Ferrous metal, including cans, recovered from solid waste must compete with other sources of iron and steel scrap. Of the three major markets which exist, the western U.S. copper precipitation market, where recovered can metal is preferred because of its high surface area per unit of weight, is usually unavailable because of distance and shipping cost; the detinning market has usually been unavailable because of marginal profit and aluminum contamination; and the steelmaking market is undependable because the contaminants in recovered ferrous metal make this a material of last resort.[11] The most favorable

Table 90

CALCULATION OF POTENTIAL VALUE FOR FUEL PREPARED FROM MUNICIPAL SOLID WASTE BASED ON LOWER HEATING VALUE

	Coal A	Coal B	Coal C	Prepared Fuel*	
				Range	Average
Composition, Wt.					
Ash	10.70	13.0	5.00	7.6-31.3	16.8
Sulfur	4.20	0.5	0.92	0.04-0.20	0.10
Hydrogen	4.35	1.3	5.12	-	(3.55)*
Carbon	61.52	70.6	77.13	-	(21.12)*
Moisture	10.80	11.0	3.50	11.1-66.3	30.3
Nitrogen	1.25	0.8	1.49	-	-
Oxygen	7.18	2.2	6.84	-	(28.13)*
	100.00	100.0	100.00		(100.00)
Higher Heating Value					
calories/gram	6,278	6,239	7,639	1274-4218	2768
(BTU/lb)	(11,300)	(11,230)	(13,750)	(2293-7593)	(4983)
Lower Heating Value+					
calories	5,986	6,074	7,349		2403
(BTU/lb)	(10,774)	(10,934)	(13,229)	-	(4326)
Equivalent Values					
$/10^6 kilocalories#	6.67	6.67	6.67	-	6.67
($/10^6 BTU)	(1.68)	(1.68)	(1.68)	-	(1.68)
$/metric ton	40.00	40.59	49.11	-	16.06
($/short ton)	(36.29)	(36.82)	(44.55)		(14.57)

---

* Data from Table 5. Balance of composition, shown in parentheses, assumed to be cellulose for purposes of this calculation.

+ By calculation, correcting higher heating value for unavailable heat due to water in flue gas (from moisture and hydrogen combustion) in vapor rather than liquid form. All heating values assumed at 15.6 C (60 F).

# Based on lower heating value

counteractants to this picture is the emerging resource recovery technology for separate recovery of other metals and clean ferrous metal recovery, and the emergence of industrial organizations specializing in the cleaning and purification of crude recovered metals for resale to processors. In some cases, compaction of recovered metal to improve handling may be necessary.

To assure stable markets for recovered ferrous metal, cooperative testing and long term contracts with purchasers are recommended, even at prices well below those which sometimes exist during peak scrap demand. Escalation clauses should be considered based on market conditions and contamination level. A stable supply of reasonably priced scrap may encourage foundries and steelmakers to devise systems with the capability of handling contaminated ferrous scrap. Both the potential for use and the problems have been demonstrated in extensive test work.[28]

Aluminum

Increasing costs for electrical power and for aluminum ores have created considerable incentive for maximizing aluminum recycle. The high price being offered for scrap aluminum has encouraged recovery at the source through volunteer organizations and others.[11] Although it is expected that a considerable amount of aluminum will still find its way into solid waste, its concentration in the waste is very low, on the order of one weight percent or less. As shown earlier in this Chapter, even at low concentration it is well worth recovering because of the high price. As with ferrous metals, contamination is a very important consideration, increasing reclaiming costs, and careful attention must be given to this problem.

An interesting possibility exists for installing aluminum scrap electrical melting furnaces to produce aluminum ingot for sale to fabricators. In thermal processing facilities where electrical power is produced, this possibility is even more attractive. Such an operation could handle both aluminum recovered from solid waste and aluminum separated at the source, for example from volunteer organizations.

Other Nonferrous Metals

As shown earlier in this Chapter, other nonferrous metals such as copper and zinc can be recovered from solid waste as mixed metallics, or possibly as separate metals by further processing. Many nonferrous metals are in short supply worldwide, providing considerable incentive for improving recycling methods.

Glass Cullet

A good market exists for clean color-sorted glass cullet in many parts of the United States. These materials are used in existing glass melting furnaces along with the raw materials normally used in glass making. The development of adequate methods to recover clean glass sorted into flint (colorless), amber, and green colors is the critical problem in this market, but present technology appears to be expensive. If good quality glass can be produced consistently, it should find ready market acceptance in glass melting furnaces, because of savings in energy consumption and advantages in air pollution control as compared to the use of raw materials for glassmaking. The potential for unsorted glass is much less favorable.

Plastics

Although no market now exists for plastics recovered from solid wastes, it is possible that as technology develops for recovering plastics, markets could become available either through existing reclaiming operations, or by the development of new products which can use the reclaimed plastics. Certainly the high price paid for clean segregated plastic scrap provides considerable incentive for improved technology.[11] Unfortunately, the very wide variety of plastic materials and the low concentrations present in solid waste preclude any simple answer to the problems of separation and salvaging. At the moment it appears that, at least in thermal processing facilities, the best outlet for plastics is in the thermal process itself, either recovering heat from combustion or fuels by pyrolysis.

Flyash

The principal sources of flyash in thermal processing facilities will be from air pollution control equipment in incinerators, and in boilers where fossil fuels and prepared refuse are fired together. These ashes may be available wet or dry depending upon the particular forms of air pollution control and of ash handling. Some important uses of flyash from coal fired steam boilers have been developed, primarily in construction materials, but these uses consume only a minor part of the total available ash.[26] Flyash from incinerators will compete in the same market, either successfully or unsuccessfully, depending upon the particular location and aggressiveness of the facility management. Fortunately, sterile flyash is not an objectionable fill material and can be disposed of where fill is desired, in special landfill sites, or in sites where a variety of wastes are accepted.

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CHAPTER XVIII

OPERATION AND MAINTENANCE

Having a well designed, fully equipped thermal processing facility is a prerequisite to achieving satisfactory plant performance with acceptable expenditures of time and money for operation and maintenance. While the importance of at least adequate facilities may seem obvious, it is a fact that many plants are poorly designed, or are forced to operate at above the capacity for which they were designed. In other instances, the characteristics of the solid waste burned has changed since the plant was designed and performance is adversely affected. In order to achieve the required throughput while at the same time meeting burnout criteria and effluent control requirements, plant management people often are forced to increase operating and maintenance staffs, make expensive equipment modifications, and justify frequent replacement of critical equipment or parts.

Having acknowledged the importance of design to successful thermal processing of solid wastes, one must guard against the tendency to overemphasize positive and negative roles of the design engineer, which is past history, while overlooking the important everyday contributions of operation and maintenance. Poor design is difficult to overcome, but operating management can make or break adequately designed facilities.

Management and Personnel

As a community plans and builds a thermal processing facility, it should also plan for the management and personnel necessary to operate it. The plant supervisor should be involved as early as possible during the design and construction period, but at least several months before construction is completed so that he can become thoroughly familiar with each major component as it is installed. Operating personnel should be obtained early enough so that they can work closely with representatives of the manufacturers and contractors when the facility is in the latter stages of construction and put through the acceptance tests. In this way, personnel can be trained in proper operation, maintenance, and repair.

At the outset, the management, including the plant superintendent, should develop a table of organization showing the number of shifts, number and types of personnel per shift, and standby and maintenance personnel. Approximate manning requirements for municipal refuse incinerators are given in Table 91. Several methods of job classification exist; whatever method is used should have sufficient flexibility to insure accomplishment of unforeseen as well as defined tasks. Rigid job titles that tend to limit operating personnel duties should be avoided.

Staffing needs vary with the size and type of facility, number of shifts, organized labor regulations (including working hours, vacations, fringe benefits), and the extent of plant subsidiary operations, such as heat

Table 91

ESTIMATED MANNING REQUIREMENTS FOR MUNICIPAL INCINERATORS

Classification of Personnel	No. Required
Administrative[1]	
Plant Superintendent	1 per plant
Clerical	1-3 per plant
Other Administrative Personnel (including engineers)	0-3 per plant
Operation[1]	
Foreman	1 per shift
Operators[2]	1-3 per shift
Stationary Engineers[3]	1-3 per shift
Weighmasters	1-2 per shift
Cranemen	1-2 per shift
General Plant Labor[4]	1-4 per shift
Truck Drivers (for residue disposal)	1-3 per shift
Maintenance[5]	
Mechanical	3-23 per plant
Piping	
Electrical	
Welding	
Instrument	
General Maintenance Labor	

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[1] Staff requirements vary with plant type as well as with capacity over the 10-80 metric ton/hour range considered. For plants operating more than five 24 hour days, four or more shifts of workers may be required.

[2] Furnace operators may include one or more licensed firemen per shift where heat recovery is practiced.

[3] Where waste heat boilers are used, State laws usually require that operators be licensed boiler engineers.

[4] Including tipping area, charging floor, conveyors, and residue handling and yard work.

[5] Maintenance staff requirements vary widely depending upon the extent to which central shop facilities and contract maintenance are used.

recovery and salvage. A useful target for man-hours in efficient incinerator operation would be 0.5 per metric ton of solid waste processed, or less, excluding residue disposal and major repair work. This target may be difficult to meet in very small operations, or operations where resource recovery is practiced. Caution should be exercised by management not to over-staff during startup operations because it may be difficult or impossible to reduce the size of the staff at a later time.

Management should provide sufficient employment incentives to attract suitable personnel. An acceptable working environment, equitable pay, advancement opportunities and training, retirement and other fringe benefits, and employment security are essential.

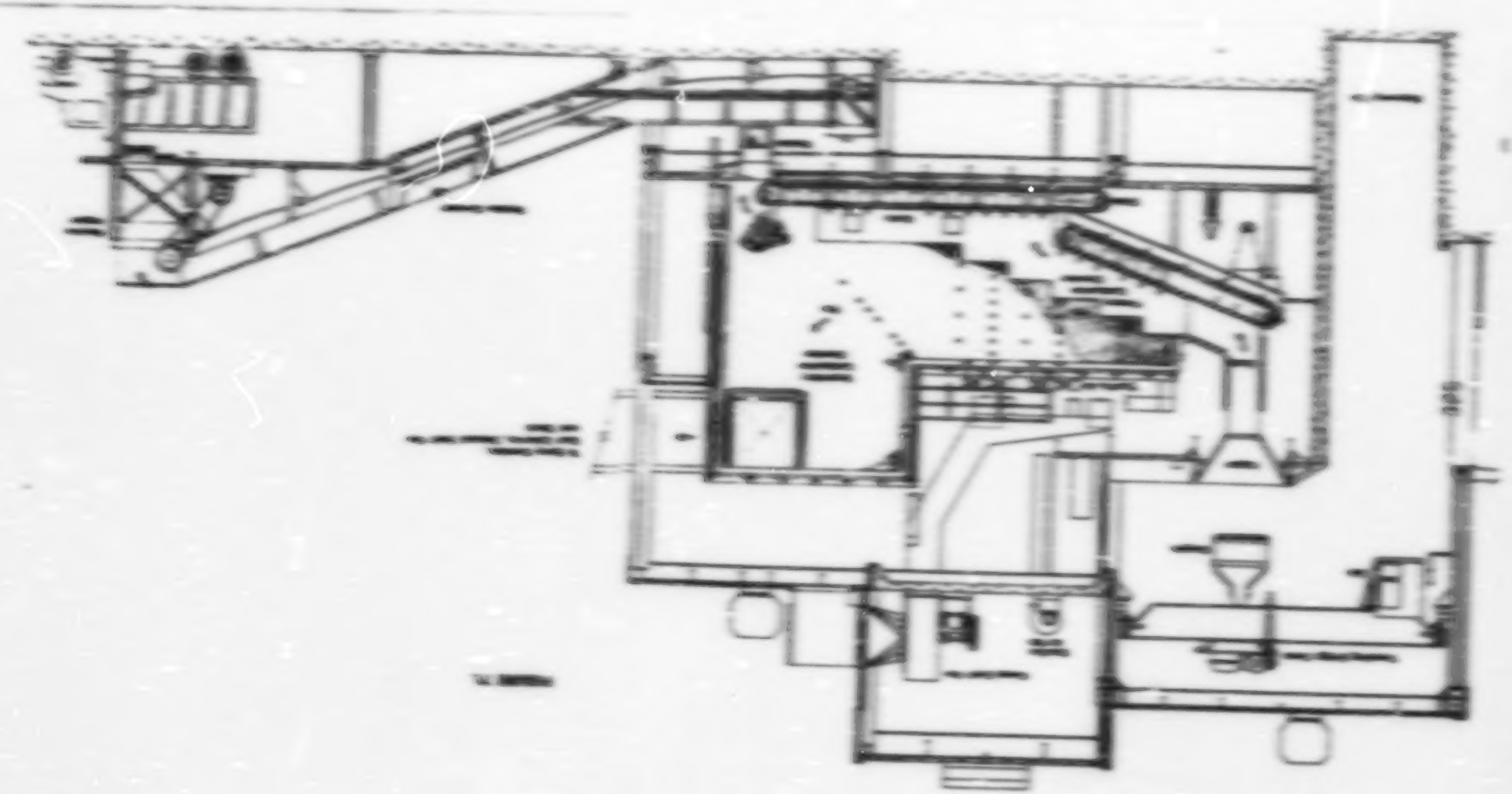
Operation Guides

Flow Diagram. An attractive flow diagram, pictorial drawing, or scale model of the plant should be displayed in a convenient location, such as the main entrance or the control room. This diagram or model should show all major equipment components by name and function. An example flow diagram is shown in Figure 71. The reader will note that the drawing illustrates how the solid waste and the resulting gases and residues pass through the plant. Uses of the drawing or model include explaining the process to visitors and training of plant operating and maintenance personnel to help in visualizing how the various equipment components function together.

Engineering Drawings. At least one complete set of detailed engineering drawings has to be maintained at the plant for reference by operating and maintenance personnel. Additional sets of drawings should be filed with the solid waste disposal agency which has jurisdiction, and other regulatory agencies as required.

Safety Rules and Procedures. Thermal processing facilities have a number of built-in hazards: deep storage pits; moving parts of motors, fans, etc.; possible smoke hazards, particularly in forced draft plants; fire hazards; conveyors; moving vehicles; shredders; and various tanks, platforms, and other possible sources of serious falls. Therefore, a routine, short training course for new employees should include safety related aspects of the job as well as job duties. Also, safety procedure and practices should be a part of refresher training.

A positive, supervised plant-safety program is essential. Fires may occur in the storage pit and in other areas of the plant. Established procedures will assist the plant personnel to safely control these blazes until outside assistance is obtained. All possible openings and moving parts should be as well guarded as possible, consistent with efficient operation. First-aid equipment and respirators should be readily available and their use insisted upon. Face masks for stokers should be a standard requirement. Particular attention must be paid to tipping-floor operation;



[illegible]

a fall into a 30 foot pit is not to be taken lightly. Crane operation bears careful watching, together with crane maintenance; a broken cable can cause extremely serious injuries. Above all, the plant superintendent and shift foremen should be constantly alert for unsafe practices or physical conditions. Without their constant supervision, unnecessary accidents are going to occur, and such accidents can be costly in both personnel injury and plant downtime. Federal occupational safety and health (OSHA) standards provide useful guidelines in this area.

Operation Manual

Proper operating procedures and competent operators are probably the most important elements in successful thermal processing.[2] In addition to carefully selecting operators and other plant personnel, they must be properly trained. The key document used in training these persons is the operating manual.

The operating manual will be the basis for initial and followup training sessions. It will also continue to serve as a valuable reference, especially when adjustments and modifications in plant operation are made. An adequate manual will include a presentation describing the mission of the plant, the responsibilities and functions of plant personnel, rules and procedures for safety and good housekeeping, record keeping procedures, a description of the process, and diagrams showing the flow of material through the plant. A section will be included which provides detailed operating instructions for each major item of mechanical equipment. The manufacturers operating instructions, drawings and spare parts lists should be available for quick reference by plant operators. Special emphasis should be given to the function of the instrumentation provided and how it should be used to promote efficient operation, avoid physical (including thermally caused) damage to the process equipment and structures, and at the same time achieve the required levels of emissions to the air, water, and land environment.

The manual should discuss frequently occurring operating problems and describe the recommended procedures for solving them. Examples of routine operating problems include clogging of the feed chute by oversized objects; fire back through charging chute; jamming of moving grates, mechanical stokers or conveyors by clinkers, tramp metal, etc.; failure to control combustion temperature within specified limits; incomplete burnout of the residue; clogging of storage pit and residue-conveyor drains; smoky conditions within the plant; and unacceptable stack emissions. The operating manual and training program should include the procedures for:[3]

1. Plant startup from a cold start.
2. Plant startup after an emergency shutdown.
3. Routine operation.
4. Routine shutdown.
5. Emergency shutdown.
6. Lubrication and routine servicing of equipment.

Also, an extensive review of the causes of operating problems in municipal incinerators and suggested procedures to eliminate those problems has been compiled for use in plant operations.[4] While it will not be possible to describe every situation which might occur, a carefully prepared operating manual will materially aid the operators in achieving the high degree of proficiency desired. Finally, the manual should be updated frequently, especially during the first year of operation, to reflect procedures instituted to overcome problems, and after major equipment and control changes have been made.

Maintenance and Repairs

Records. A records systems should be established by the plant supervisor wherein periodic maintenance of each incinerator component is scheduled to be done by specific personnel. In contrast, certain maintenance, such as cleaning, lubrication, and adjustment of equipment, may be done by operating personnel as part of their daily or weekly tasks and need not be recorded. Certification that maintenance has been performed should also be recorded. Card files set up with an automatic reminder procedure will provide a permanent record of maintenance for each item of equipment and guard against omission of scheduled maintenance. Properly certified maintenance records, tabs, or seals, may also be affixed to the equipment as maintenance is performed. Major repairs, such as the replacement of refractories, will necessarily be recorded separately. Unscheduled repairs and breakdowns should be handled promptly and carefully recorded so that the cause can be determined and corrected.

Maintenance and Equipment Manuals. Data required by maintenance personnel include that which will assist in locating causes of equipment malfunctions, and provide the information necessary to complete repairs. A complete set of structural, equipment layout, piping and instrument, electrical, and heating and ventilating drawings is essential to proper plant maintenance. Maintenance manuals provided by the equipment contractor should describe the servicing or repair of each major item of equipment, including shop and assembly drawings, parts lists, and trouble-shooting instructions. Special procedures for operating maintenance machinery and welding equipment, as well as safety rules and good housekeeping procedures, should also be available for easy reference. Methods used for the training of maintenance employees will vary somewhat depending upon their level of experience when hired, and the maintenance needs of the plant.

Routine Maintenance. The importance of routine or preventive maintenance cannot be overly stressed. Study of maintenance records will show which equipment is most subject to failure or malfunction. Those equipment items should be maintained on a regular schedule and/or during normal shutdowns. This will reduce the possibility of unexpected outages due to inadequate routine maintenance. If frequent outages persist, consideration should be given to replacement or redesign of the troublesome equipment.

Inspection Procedures. Components subject to rapid wear or damage should be inspected weekly at a time when such components are not being operated. At each inspection, a thorough report should be made, including condition of the furnace, repairs performed, and experiation of future repairs or major overhaul. Plant performance records and maintenance files can be used to determine when major repairs are necessary. All equipment subject to wear, corrosion, erosion, or stress failure should be thoroughly inspected at least annually and more often if necessary. Complete inspection reports should be maintained.

Repairs. In many larger plants, the maintenance staff will be expected to perform all but the most major repairs. Major structural repair, refractory replacement, and repair of large motors is sometimes excepted. In large municipalities, central repair facilities are sometimes available to perform major repairs. In smaller plants, plant personnel will not normally be expected to perform major repairs on equipment, building, or facilities. Other municipal personnel may perform some repairs, and certain repairs will require special contract services.

When major overhauls are being made, the units remaining in service should not be overloaded to make up for the loss of capacity. The amount of solid waste equivalent to the "down" unit's capacity should be diverted to approved disposal facilities. Ideally, extensive repairs should be scheduled during the season when waste generation is lowest.

When general wear and tear accumulates to the point that continued operation is no longer economically feasible or prudent without major reconstruction, the abandonment or demolition of the facility must be considered. Good management demands that such determination be made in time to arrange for the necessary financing and construction of new facilities. Since this process may take several years, adequate lead time is essential. A capable plant operator will be able to aid in this decision.

Management should keep abreast of new developments and decide whether operation can be improved. The costs of revisions, expected life of the plant, temporary disposal alternatives, and financial considerations enter into these decisions. Unfortunately, the updating of incinerators by redesign and reconstruction has been the exception rather than the rule.

In many instances, facilities are built with provisions for future enlargement or for later addition of equipment. Here again, performance evaluation will guide the decisions of when to modify equipment or to enlarge capacity.

Maintenance of Buildings. Although certain parts of a plant are inherently dirty, dusty, or difficult to keep clean, devices to reduce accumulation of dust and dirt, water, or debris should be installed, and personnel should spend some time during the shift to maintaining a clean workspace. Specific assignments to such jobs is essential. Misuse of employee facilities, such as accumulating salvage items should not be permitted. In some instances, poor housekeeping creates fire or safety hazards. Lighting fixtures and bulbs should be kept clean to provide acceptable illumination at all times. Auxiliary lighting equipment should be maintained for inspection purposes and for use in emergencies.

Maintenance and Repair Costs. The cost of proper maintenance and repairs varies with the size, type, and age of the plant but can be expected to run between 14 and 20 percent of the operating costs (excluding depreciation and interest), split about equally between labor and materials.[6] Good management will budget for annual maintenance and repair work based on experience and inspection reports, including periodic major replacements and modernization.

Performance Records

A detailed data acquisition and cost accounting system should be established, and complete records of capital, operating and maintenance costs should be kept. Manual recording of data or primarily automatic data acquisition may be used. The system adopted should be detailed enough to permit identification of those portions of the operation which are contributing to unnecessarily high costs. These data also make it possible to monitor the efficiency of the operation in terms of the weight and volume reduction of the solid wastes processed; ability to operate at acceptably high and sustained rates of throughput; compliance with air, water and solid residue discharge requirements as they affect the environment; and performance of salvage and heat recovery operations. Often overlooked is the value of reliable operating data in designing new or expanded thermal processing plants. In addition to data sheets, permanent operating logs kept by the operators and/or the foremen provide a daily record of problems, solutions to problems, explanations for excursions of temperature and other important variables, routine and non-routine maintenace, etc.

Criteria Used in Data Collection. Maintaining adequate records of day-to-day operations is necessary in order to monitor the process efficiency and plant costs. These data should be recorded in convenient form for review, and should include sufficient information to permit appropriate decisions to be made which will improve the operations. Since the successful operation of the plant is dependent on the adequate recording and use of records, administration of record keeping practices should originate at the highest level of plant management, usually the plant superintendent.

Records will normally be reviewed by the supervisor of the person or persons responsible for their preparation. The frequency of review should be consistent with the purposes for which the records are kept. For example, critical air flows, temperatures, emission data, and the like should be under constant surveillance by the plant operators of the foremen, since prolonged upsets could cause serious complications or plant shutdown. Data relating to storage pit contents, daily throughput, residue quality, and the like may require less frequent monitoring, such as for example, once each shift, or each day. The costs associated with keeping good records and insisting on timely review for corrective purposes can produce handsome dividends in terms of better plant operation and lower overall costs.

Use of Operating Data in Cost Accounting. Many of the same data used for process monitoring will be used in implementing the cost accounting system. One system of cost accounting is provided in Zausner's "An Accounting System for Incinerator Operations."

The following will illustrate how plant records might be used to improve plant operations. It is recognized that the numbers of man-hours required for maintenance in each particular area of the plant will be one of the significant factors in the cost of operation. The particular cost items can be reviewed in terms of their contribution to the overall operating cost or cost per unit of throughput. When periodically reviewed, along with other cost data, significant changes in these maintenance costs will be detected. Timely detection allows corrective action to be taken before extraordinary sums are expended. The corrective action may include, for example, increased emphasis on preventive maintenance, replacement of obsolete equipment, or whatever other action is indicated.

From the foregoing, it is apparent that a well conceived cost accounting system can be a useful means of attaining an effective plant operation at minimum cost. The success of any cost control system depends to a great extent upon the quality of the data provided to it.

Use of Operating Data in Process Operation. Aside from cost control and other record keeping purposes, recording process data alerts operators to deterioration in automatic control systems and to changes in operations requiring control adjustment. This is useful in all operations, but is especially important in plants equipped with a minimum of automatic controls. For example, changes in incinerator temperature may require adjustments to maintain performance and to prevent damage to equipment. Where heat recovery equipment is used, monitoring is required to maintain the desired performance and to detect mishaps, such as pressure loss due to rupture of boiler tubes. Operating data is also used to make adjustments in personnel assignments, schedule repairs, and make periodic reports to regulatory agencies concerning environmental matters.

Thermal processing plants other than incinerators require special attention. For example, some pyrolysis processes convert solid waste to combustible fuel gases which are burned in a waste heat boiler. Careful control of pyrolysis conditions are required to insure an adequate supply of fuel to the boiler, to insure safe operation, and to protect the processing equipment. In all pyrolysis processes monitoring is required to insure adequate performance and safety of each critical subsystem, such as the pyrolysis reactor, condensers for liquid fuel recovery, refuse driers, etc.

Important Operating Data

Some of the important operating data are discussed below with regard to record keeping. A detailed analysis is required for each new plant, with periodic updating as data needs change.

Incoming Solid Waste. Plant records should indicate the total weight of solid waste received during each shift as well as the number of vehicles arriving, identity of vehicles, and the source and nature of solid waste received. The primary responsibility is with the weighmaster, as discussed in Chapter VII.

Rate, Temperature, and Pressure Data. Operators should record temperature at frequent intervals, unless such data is recorded automatically. Grate speeds (or rate of operation) should be noted throughout the shift. Air and gas volumes and distribution should also be reported. All readings should be made at least hourly and any major changes noted. Some instruments give indirect readings which may require operator aids such as conversion charts for data interpretation.

Residue. Operators should record the time or rate of residue removal. Residue should be weighed on the scale as it leaves the plant, and the amount removed should be recorded. Moisture correction is necessary for proper interpretation of residue weight. The dry weight of residue can be estimated by periodically obtaining the average moisture content. Residue quality should be visually determined and recorded. Flyash records should be kept when this material is handled separately.

Water Consumption. Water used for quenching and for scrubbers should be recorded from meter readings or by other means at least at the start and end of each shift.

Stack Discharges. Records of stack discharge characteristics commonly include smoke indicator readings, Ringelmann readings, and analyses from stack sampling. Precise stack sampling is expensive, allowing only infrequent testing of this type.

Wastewater Discharges. Flow rates and analytical data obtained from periodic samples taken at the inlet and outlet of the treatment facilities should be recorded. Use of a recording instrument for effluent pH is strongly recommended and daily records of the quantities of acid, caustic and other treatment chemicals should be kept. If water recycling is practiced, the flow rate should be recorded for comparison with the water consumption and discharge meter readings.

Salvage and Other Resource Recovery. Data showing the amount of iron or other salvage recovered should be recorded daily. Accurate records must be kept of fuel produced by pyrolysis.

Personnel Records. Accurate personnel time and cost records should be kept so that performance can be evaluated on the basis of operating cost per ton and on the basis of man-hours per ton. Costs of operating and maintenance labor should be kept separately. Also, these costs should be identified by the appropriate operation to which it applies, e.g., receiving, salvage, volume reduction (burning), energy recovery, and effluent handling and treatment. Direct and indirect costs should be included in the total cost of operation.

Supplies, Material, and Equipment. All supplies, material, and equipment utilized in operation and maintenance should be recorded and charged against thermal processing, even though provisions or purchases may be made by another department. Major maintenance (such as rebuilding of refractories), whether done by contract or by plant personnel, should be recorded as cost items separate from operation. Thus, both the cost of repairs and maintenance and the cost of plant operation can be determined.

Methods of Preparing Data Records

Recording of plant operating data is done either manually or automatically. As municipal thermal processing plants become more sophisticated and complex, the trend is toward a greater reliance on automatic data collection.

Manual records are required when the information is non-routine in nature or when automation is not justified. Prepared forms are often used to assist in manual record keeping. Examples of manual records include time sheets, operators' logs, laboratory reports, maintenance logs, materials requisitions, and performance reviews.

Where manpower can be saved, or where operating efficiency can be improved, it may be possible to justify automatic data acquisition equipment. Recorders for various process parameters, such as temperature, air flow, stoker speed, wastewater pH, and smoke density are familar to operators of modern plants. Measurements made at various plant locations are often transmitted to recorders in a central control room. Using electronic instruments and a computerized data acquisition system, it is even possible to print out these measurements in tabular form by use of a teleprinter. More frequently, however, tabular summaries of chart records are compiled manually by shift personnel at hourly intervals. Manual and automatic options for process data are similarly available for truck weight records.

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APPENDIX A

INVENTORY OF MUNICIPAL SOLID WASTE THERMAL PROCESSING FACILITIES

The following inventory of incinerators and their status was supplied by the American Society of Mechanical Engineers (ASME). The status of the various plants is as of December 1974.

List of Plants†

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
CONNECTICUT		
* Ansonia	200	
Bridgeport (Bostw. Ave.)	300	
Bridgeport (Asylum St.)	200	
Darien	130	
East Hartford	350	
Greenwich (#1)	150	
Greenwich (#2)	250	
Hartford	600	
New Britain		300
New Canaan		60
* New Canaan	125	
New Haven	720	
New London	120	
Norwalk	360	
Stamford	400	
* Stamford (bulky waste)	100	
* Stamford	360	
Stratford	264	
Waterbury	300	
West Hartford	300	
West Haven		300
FLORIDA		
Broward Co. #1	300	
Broward Co. #2	300	
**Broward Co. #2	300	
Clearwater		300
Coral Gables		300
Dade Co. (N. East)	300	
Ft. Lauderdale (#1)	450	
Ft. Lauderdale (#2)	250	
Hollywood		450
Jacksonville		300
Miami (Coconut Grove)		300
Miami (20th St.)	900	
Orlando		150
* Reedy Creek (Disney W.)	150	
St. Petersburg		[illegible]00
Tampa	1000	

* Not on A.D. Little 1969 list
**Plant capacity currently 600 T/D

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†Source: ASME, Jan. 1975

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
GEORGIA		
Athens		50
Atlanta (Mayson)		350
Atlanta (Hartsfield)		750
DeKalb County		600
HAWAII		
Honolulu (Kapalama)	200	
Honolulu (Kewalo)	200	
* Honolulu (Waipahu)	600	
ILLINOIS		
Aurora		40
Chicago (Medill)		720
Chicago (Calumet)	1200	
*Chicago (Northwest)	1600	
Chicago (Southwest)	1200	
Cicero (Stickney)	500	
Evanston		180
Melrose Park		250
Schiller Park		250
Skokie		150
INDIANA		
Bloomington		100
East Chicago	450	
Indianapolis		450
New Albany		170
*Shelbyville	150	
KANSAS		
Dodge City		35
KENTUCKY		
Frankfort		150
Lexington		200
Lexington		150
Louisville	1000	
* Ludlow	50	
Paris		100
Winchester		100

* Not on A.D. Little 1969 list
**Plant capacity currently 600T/D

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
LOUISIANA		
Gretna		100
Jefferson Parish		90
Jefferson Parish		400
Morgan City		30
New Orleans (Algiers)	200	
New Orleans (East)	400	
New Orleans (Fla. Ave.)	400	
New Orleans (7th St.)	400	
* New Orleans (St. Louis St.)	450	
* St. Bernard Parish (Chalmette)		100
Shreveport (Minden)		250
* Shreveport	200	
MARYLAND		
Baltimore (#3)	600	
Baltimore (#4)	800	
* Baltimore (Monsanto)	1000 (U.C.)	
Montgomery County		1400
Salisbury	125	
MASSACHUSETTS		
Belmont	150	
Boston (South Bay)	900	
Braintree	240	
* Brockton (E. Bridgewater)	600	
Brookline		180
Cambridge		150
Dedham		100
Fall River	600	
* Framingham	500	
Framingham		200
Holyoke	225	
Lawrence		300
Lowell	400	
Marblehead	80	
New Bedford		225
Newton		240
Newton	500	
Pittsfield		180
* Reading	144	
Salem	140	
* Saugus	1200 (U.C.)	
Somerville		450
Waltham	150	
Watertown	320	
Wellesley		150
Weymouth	300	
Winchester	100	
Worcester		450

* Not on A.D. Little 1969 list
U.C. - Under construction

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
MICHIGAN		
Central Wayne County	800	
Detroit (St. Jean)	200	
Detroit (N.W.)		450
Detroit (Central)		525
Detroit (24 St.)		500
* Grosse Pt.-Clinton (Macomb Co.)	600	
River Rouge	50	
S.E. Oakland County	600	
Trenton		100
MINNESOTA		
Minneapolis		300
MISSISSIPPI		
Picayune		144
MISSOURI		
St. Louis (North City)	400	
St. Louis (South City)	400	
NEBRASKA		
Omaha		375
NEW HAMPSHIRE		
Manchester	100	
NEW JERSEY		
Ewing	240	
Hamilton Township		99
Jersey City		600
Perth Amboy		150
Princeton		120
Red Bank		120
* Red Bank	48	
Spring Lake		30
* Wanaque		300

* Not on A.D. Little 1969 list
U.C. - Under construction

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
NEW YORK		
Amsterdam		120
Babylon (#1)	300	
Babylon (#2)	400	
Beacon	100	
Binghampton		300
Buffalo (East Side)		600
Buffalo (West Side)	600	
Canajoharie	50	
Carmel	40	
Cheektowaga		100
Corning		80
Eastchester	200	
Freeport	150	
Garden City	175	
Hempstead (Merrick)	600	
Hempstead (Oceanside)	750	
Huntington (#1 & #2)	300	
Huntington (#3)	150	
Islip (New Sayville)	300	
Lackawanna	150	
* Lawrence	200	
Long Beach	200	
Mt. Kisco		40
Mt. Vernon	600	
Newburgh	240	
New Rochelle	400	
NYC (Betts)	1000	
NYC (Gansevoort)	1000	
NYC (Hamilton)	1000	
NYC (South Shore)	1000	
NYC (S.W.Bklyn)	1000	
NYC (73 Street)		660
NYC (215 Street)		750
Niagara Falls		240
N. Hempstead (Denton Ave.)	200	
N. Hempstead (Roslyn Harbor)	600	
Oyster Bay (#1)	500	
Oyster Bay (#2)	600	
* Pelham Manor	85	
Port Chester	120	
Poughkeepsie		200
Ramapo		200
Rochester (E. Side)		600
Rochester (W. Side)		450
Rye	150	

* Not on A. D. Little 1969 list

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
NEW YORK (Cont'd)		
Scarsdale	150	
Tonawanda (City)	80	
* Tonawanda (Town)	250	
Tonawanda (Town)		200
Valley Stream	200	
White Plains	400	
Yonkers	650	
OHIO		
Barberton		100
Cheviot	60	
Cincinnati (Center Hill)	500	
Cincinnati (West Fork)	500	
Cincinnati (Dunbar)		200
Cincinnati (Crookshank)		200
Cleveland		500
Cleveland Heights		150
* Dayton (S. Montgomery Cty)	600	
* Dayton (N. Montgomery Cty)	600	
Euclid	200	
* Franklin	150	
* Greenhills		56
Lakewood	300	
Miami County	150	
Norwood		150
Parma	225	
Sharonville	500	
Woodville	12	
Youngstown		300
PENNSYLVANIA		
Abington		200
Allentown		270
Ambridge	150	
Bradford	200	
Delaware County (#1)	800	
Delaware County (#2)	500	
Delaware County (#3)	500	
Erie		100
* Harrisburg	720	
Lower Merion Township	250	
Meadville		80
Philadelphia (Bartram)	600	
Philadelphia (E. Central)	600	
Philadelphia (Harrowgate)	300	
Philadelphia (N.E.)	600	

* Not on A.D. Little 1969 list.

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
PENNSYLVANIA (Cont'd)		
Philadelphia (N.W.)	600	
Philadelphia (S.E.)	600	
Red Lion Borough		60
* Shippensburg	72	
West Mifflin		40
Whitemarsh Township		100
RHODE ISLAND		
Newport		120
Pawtucket	400	
Providence		320
Warwick		100
Woonsocket	160	
TENNESSEE		
* Nashville	720	
TEXAS		
Amarillo	350	
Houston (Holmes Rd.)		800
UTAH		
Ogden	450	
VIRGINIA		
Alexandria (#2)	300	
Alexandria (#1)		200
Arlington		750
* Newport News	400	
Norfolk (Lampert's Pt. #4)	400	
Norfolk (Navy Publ. Works)	360	
Portsmouth	350	
Roanoke		200
WASHINGTON, D.C.		
Fort Totten		500
Georgetown		170
Mt. Olivet		500
O Street		425
* Solid Waste Red. Center #1	1500	
WEST VIRGINIA		
Charleston		300

* Not on A.D. Little 1969 list

	Operational as of Dec. 74 T/D	Closed since 1969 T/D
WISCONSIN		
DePere	75	
Fond du Lac		90
Green Bay		150
Green Bay	360	
Kewaskum		24
Merrill		36
Milwaukee (Erie St.)		225
Milwaukee (Green Bay Ave.)		300
Milwaukee (Lincoln Ave.)		300
Monroe		60
Neenah-Menasha	300	
Nekoosa		80
Oshkosh		100
Oshkosh	350	
Port Washington	75	
Racine		120
Sheboygan	240	
* Sturgeon Bay	150	
* Waukesha	350	
Wauwatosa		165
West Allis		200
Whitefish Bay		80

* Not on A. D. Little 1969 list.

Capacities listed in this Table are, to the best of our knowledge, "nameplate" ratings confirmed by manufactururs and/or design engineers. Actual plant operating capacities may differ from these listed capacities.

Appendix B

SUMMARY OF RESOURCE RECOVERY SYSTEM IMPLEMENTATIONS

December 1975

Location	Type*	Capacity (TPD)	Products/Markets	Start-Up Date
SYSTEMS IN OPERATION (14):				
Altoona, PA	Compost	30	Fertilizer	1963
Ames, IA	RDF	400	RDF, Fe, AL	9/75
Blytheville, AR	Small Incin.	50	Steam-Industry	1975
Braintree, MA	WWI	240	Steam-Process	11/75
N-E. Bridgewater, MA	RDF	160	RDF-Utility	1974
D-Franklin, OH	Wet-Pulp	150	Fiber, Fe	1971
Harrisburg, PA	WWI	720	Steam-Heating Loop	1972
Nashville, TN	WWI	720	Steam Heating & Cooling	7/74
Norfolk, VA	WWI	360	Steam-Navy Base	1967
Palos Verdes, CA	Landfill Wells	N/A	Methane Gas	6/75
D-St. Louis, MO	RDF	300	RDF-Coal-Fired Utility	4/72
Siloam Spring, AR	Small Incin.	20	Steam-Industry	9/75
Saugus, MA	WWI	1600	Steam-Process	1976
N-South Charleston, WV	Pyrolysis	200	Gas	1974
SYSTEMS UNDER CONSTRUCTION OR SELECTED (10):				
Baltimore, MD	Pyrolysis	1000	Steam-Heating & Cooling	6/75
Baltimore County, MD	RDF	550	RDF, Fe, AL, Glass	4/76
Bridgeport, CT	RDF	1800	RDF, Fe, AL, Glass	7/77
Chicago, IL (Crawford)	RDF	1000	RDF-Utility	6/76
Hempstead, NY	Wet Pulp	2000	Electricity,Fe,AL, Glass	N/A
Milwaukee, WI	RDF	1000	RDF, Corrugated, Fe	1977
Monroe County, NY	RDF	2000	RDF, Fe, Non-ferrous	3/77
N-New Orleans, LA	Shredding & Classification	650	Non-ferrous, Paper, Fe, Glass	5/76
U-San Diego, CA	Pyrolysis	200	Liquid Fuel-Utility	7/76
St. Louis, MO (expansion)	RDF	8000	RDF-Utility, Fe, Non-ferrous, Glass	N/A
COMMUNITIES COMMITTED (29): (RFP issued, design study underway, or construction funding made available.)				
Akron, OH	WWI	1000	Steam-Heat, Cool, Process	7/78
Albany, NY	RDF	1200	RDF, Fe	N/A
Central Contra Costa County Sanitation District	RDF	1000	RDF-Sludge Incinerators	1979

* See page for code definitions.

SUMMARY OF RESOURCE RECOVERY SYSTEM IMPLEMENTATIONS

December 1975

Location	Type	Capacity (TPD)	Products/Markets	Start-Up Date
COMMUNITIES COMMITTED (28):	(continued)			
Chemung County, NY	RDF	300	RDF, Fe	N/A
Cuyahuga County, OH	RDF	1200	RDF-Steam-Industry	N/A
Dade County, FL	WWI/Wet Pulp	3000	Electricity-Utility	N/A
Detroit, Michigan	RDF/WWI	3000	Steam	N/A
Hackensack, NJ	RDF	2500	RDF-Utility, Fe	N/A
Honolulu, HI	N/A	2000	Utility	N/A
G-Lane County, OR	RDF	750	RDF	N/A
Lawrence/Haverhill, MA	WWI	3000	N/A	N/A
G-Lexington-Fayette Urban County Gov't, KY	WWI	750	Steam, Fe	1977
Memphis, TN	WWI	2000	Steam/RDF	N/A
Milwaukee, WI	RDF	1000	RDF, Fe, Paper Corrugated	N/A
Minneapolis-St. Paul	Pyrolysis/ Sludge	360	Gas, Oil Activated Char	N/A
G-Montgomery County, OH	RDF	1600	RDF	N/A
Mt. Vernon, NY	Pyrolysis	400	Gas-Electricity	1978
New Haven, CT	WWI	1800	Steam-Fe	N/A
Onondaga County, NY	WWI	1000	Steam-Heat & Cool, Fe	N/A
E-Pompano Beach, FL	Methane Rec.	50	Methane	N/A
D-Palmer Township, PA	RDF	150	Fuel-Cement Kiln	N/A
Portland, OR	RDF	200	RDF-Fe	N/A
Riverside, CA	Pyrolysis	50	Prototype/Demo	N/A
Salem, Lynn & Beverly	N/A	750		N/A
Seattle, WA	Pyrolysis	[illegible]	Methanol-Ammonia	N/A
Smithtown, NY	Materials Separation	1000	Hand Sort	11/77
Westchester County, NY	N/A	1300	N/A	N/A
D-Wilmington, DE	RDF/Sludge	300	Fe, AL, Glass RDF, Compost	N/A
Wisconsin Recycling Auth.	N/A	1200	N/A	
COMMUNITIES WHICH HAVE COMMISSIONED FEASIBILITY STUDIES (51):				
Anchorage, AK		500		
Appleton, WI		N/A		
Auburn, ME		200		
Allegheny County, PA		2000		
Babylon, Huntington & Islip, NY		3000		
Cowlitz County, WA		100		
Columbus, OH		N/A		
Dallas, TX		N/A		
DeKalb County, GA		1000		

SUMMARY OF RESOURCE RECOVERY SYSTEM IMPLEMENTATION

December 1975

Location	Type	Capacity (TPD)	Products/Markets	Start-Up Date
COMMUNITIES WHICH HAVE COMMISSIONED FEASIBILITY STUDIES (52): (continued)				
Dubuque, IA		500		
District of Columbia (Metro Area COG)		750		
G-Denver, CO		1200		
Dutchess County, NY		700		
Erie County, NY		2000		
Fairmont, MN		150		
Ft. Lauderdale, FL		200		
Grand Rapids, MI		N/A		
Hamilton County, OH		1500		
Lawrence, NY		500		
Lincoln, NB		N/A		
Lincoln County, OR		N/A		
Marquette, MI		N/A		
Miami County, OH		N/A		
G-Middlesex County NJ		N/A		
Minneapolis (Twin Resco)		N/A		
Montgomery County, MD		1200		
Madison, WI		200		
Niagra County, NY		760		
G-New York, NY (Arthur Kill)		1500		
Oakland County, MI		N/A		
Orange County, CA		1000		
Phoenix, AZ		N/A		
Pasadena, CA		220		
Peninsula Planning Dist., VA		N/A		
Philadelphia, PA		1600		
G-Richmond, VA		N/A		
Riverview, MI		N/A		
Rochester, MN		N/A		
St. Cloud, MN		N/A		
Salt Lake County, UT		750		
S.E. Va. Planning District		1500		
Springfield, IL		N/A		
Springfield, MO		1000		
Tallahassee, FL		N/A		
Tampa/St. Petersburg, FL		N/A		
Toledo, OH		1200		
Tulsa, OK		N/A		
G-Tennessee Valley Authority		2000		
Western Berks Refuse Authority, PA		250		
Western Lake Superior San. Dist.		400		
Winnebago County, IL		N/A		
Wyandotte, MI		1000		

SUMMARY OF RESOURCE RECOVERY SYSTEM IMPLEMENTATION

December 1975

Code

D--EPA Demonstration Grant
G--EPA Implementation Grant
N--Non-EPA Demonstration Facility
E--Energy Research & Development
Administration Grant
WWI--Waterwall Incinerator

AL--Aluminum
FE--Ferrous (magnetic metals)
RDF--Refuse derived full

Compiled by the Office of Solid Waste Management Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

Appendix C

TABLE OF ABBREVIATIONS

ACFM = actual cubic feet per minute

B and Bbl = barrel(s) (42 U.S. gal)

Cal = calories

cc = cubic centimeter(s)

CF = cubic feet

CFH = cubic feet per hour

CFM = cubic feet per minute

cm = centimeter(s)

CM = cubic meter(s)

CY = cubic yards

$M = thousands of dollars

$MM = millions of dollars

ft = feet

ft^3 = cubic foot

gal = gallon(s) (U.S.)

g = gram(s)

GPM = gallons (U.S.) per minute

gr = grains

Hg = mercury

hr = hour(s)

in = inch(es)

Kcal = kilocalories

kg = kilogram(s)

lb = pound(s)

m^3 = cubic meter

min = minute(s)

ml = milliliter(s)

mm = millimeter(s)

MT = metric ton(s)

MT/hr = metric tons per hour

NCM = normal cubic meter(s) (0 C, 1 atm or 70 F where indicated)

SCF = standard cubic feet (60 F, 1 atm; or 70 F where indicated)

SCM = standard cubic meters (70 F, 1 atm)

ST = short tons

ST/day or ST/D = short tons per 24 hour day

tons/ton or tons per ton always refers to consistent weight units, for example MT/MT, ST/ST, Kg/Kg, lbs/lb

TPD = short tons/day

vol = volume

WG = water gage or water column (pressure differential)

wt = weight

yr = year(s)

Appendix D

CONVERSION FACTORS

B x 42 = U.S. gal

BTU x 252 = calories

°C = (°F-32) ÷ 1.8

$/MG x 0.907 = $/ST

°F = (°C x 1.8) + 32

ft x 0.3048 = meters

Cal x 3.968 x 10^{-3} = BTU

Cal/g x 1.80 = BTU/lb

CF x 0.02832 = CM

CM x 35.31 = CF

grains/SCF x 2.29 = grams/SCM

grams x 15.43 = grains

in x 2.54 = cm

in H_2O x 1.868 = mm Hg (pressure differential)

kcal x 3.968 = BTU

kg x 2.2046 = lbs

lbs x 7000 = grains

lbs x 0.454 = kg

lbs/CF x 0.01602 = g/cc

lbs/CF x 27 = lbs/CY

lbs/CY x 1.308 = lbs/CM

MT x 1000 = kg

MT x 2205 = lbs

MT x 1.1025 = ST

SCF (60 F, 1 atm) x 0.0268 = NCM (0 C, 1 atm)

SCF (70 F, 1 atm) x 0.0263 = NCM (0 C, 1 atm)

SCF (70 F, 1 atm) x 0.0283 = SCM (70 F, 1 atm)

ST x 2000 = lbs

ST x 0.9070 = MT

(ST/24 hr) x 0.0378 = MT/hr

60 F = 15.6 C

70 F = 21.1 C

psia ÷ 14.7 = atmospheres absolute

$\frac{\text{psig} + 14.7}{14.7}$ = atmospheres absolute

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